RESTRICTED

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ATOMIC ENERGY INDOCTRINATION

DEPARTMENT OF THE ARMY SEPTEMBER 1950

RESTRICTED

What to do in case of an air burst . . .

AREA OF DAMAGE WIDESPREAD

LASTING RADIATION SLIGHT

First, obey authorities. Radiological defense personnel, trained in defensive aspects of atomic warfare, will know best what you should do. Remain calm. Any panic or hysteria will add to possible confusion. Even if radiological defense advisors are not present, common sense will help you to protect yourself. Try to understand what atomic energy is. Many people neglect reading about this subject. They think it is too complicated, or secret, or mysterious. The general principles of atomic energy and atomic warfare can be understood by anyone who will take the time and show the interest. Many good articles have been published and are available in libraries and elsewhere. The Atomic Energy Commission regularly publishes information which is easily understood and which is accurate and up to date.

Second, if an early warning of an attack is given, move to designated shelters or disperse as directed by your unit commander. Your help will be needed after an explosion occurs, so listen carefully to your commander's instructions. He may tell you where to assemble after the explosion occurs, or what duties you are expected to perform. Remember that fire fighters, rescue squads, stretcher bearers, wrecking crews, and others will be needed to help minimize casualties and damage.

Third, if there has been no early warning, but only an alert that indicates an immediate attack is expected, try to take cover. An air raid shelter, a deep basement, a subway afford good shelter. Remember that an atomic explosion is similar to an ordinary explosion except for its size and the added radiation effect. The radiation hazard will be greatly reduced, and in most cases eliminated, by finding shelter that will protect you from injury by the heat and blast.

Fourth, if adequate shelter is not available, you still can take measures against injury from flying debris. Get away from frame buildings and trees. Lie down, preferably in a ditch, behind a wall, in a ravine or depression. Try to protect your eyes from the flash by covering them with your arm; otherwise the flash could result in temporary blindness. Normal eyesight will return in a matter of minutes or hours, so do not get panicky. Remain under shelter for a few minutes after the blast to make sure that all flying debris has landed.

Fifth, try to help any injured people near you. Even if someone has been exposed to excessive radioactivity, you will not be hurt by helping him. Radioactivity is not contagious. Administer first aid to the injured if possible. Put out small fires that may have been started. Remember that many of the people in Hiroshima and Nagasaki died because they were injured and could not escape the fires that were started by the explosion. Be careful of falling buildings or large fires.

Sixth, report to the place designated by your commander. If no area has been designated, see if you can help some rescue or fire-fighting outfit that has been organized.

Seventh, when the initial rescue work, fire fighting, and evacuation of the wounded is completed, it is wise to take a shower, completely scrubbing with soap three or four times to remove any radioactive materials which may have been deposited on you. Hair, hands, and fingernails should be given special attention. If possible, change to clean clothes and shoes. Discard the clothes you were wearing while in the affected area, particularly the shoes.

Eighth, when feasible check with a radiological defense advisor and a doctor to make sure you are well and safe.

Ninth, do not spread rumors. Enough confusion will exist without adding to it. The false impressions most people have regarding the effects of the atomic bomb probably can be traced back to the rumors and false information that were spread in Japan. Remember that an air burst of an atomic bomb is primarily a blast and heat weapon. You should think more about protecting yourself from burns and concussion than from radiation. More and more accurate information is being published about radiation. It does not appear mysterious or highly dangerous once you understand what it is. Radiation is another hazard of war, just as malaria, poison gas, biological warfare, and booby traps are or may be hazards of war.

For what to do in case of a contaminating burst, see inside back cover.

DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C., *1 September 1950*

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BY ORDER OF THE SECRETARY OF THE ARMY:

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For explanation of distribution formula, see SR 310–90–1.

CONTENTS

FOREWORD

This pamphlet has been prepared to furnish instructors with information necessary to indoctrinate Army military personnel in atomic energy, in accordance with the requirements of phases II and III of the Department of the Army SR 350-80-1 (Program for Dissemination of Atomic Energy Information). The material in this publication has been obtained from many sources, particularly recently published articles.

In most of the chapters, more material has been included than normally could be used in the time assigned for the lecture. The additional information, however, will allow each instructor to select his material according to the varied needs of his classes. Charts, graphs, and tables have been used in presenting the material so as to permit the instructor to obtain considerable information in a minimum of time.

The titles of the first nine chapters coincide with the titles of the nine lectures of phase II. Each chapter contains the instructional information for the corresponding lecture. Since the lectures probably will not be given by the same instructor and the sequence may be changed, each chapter has been prepared as a self-contained unit, and, hence, contains some slight duplication of material.

For those instructors who wish to pursue the subject in greater detail than is presented in this pamphlet an annotated bibliography is included as appendix I, and a list of pertinent training films and film strips as appendix II.

Atomic energy information, both military and non-military, is expanding so rapidly that it is impossible to keep a source book such as this up to date. Therefore instructors frequently should check current literature for new material. The more important technical magazines covering the subject are listed in the bibliography.

Considerable more technical data on nuclear physics has been included in the material for chapter II than would be presented to officers or enlisted men in an indoctrination program such as is indicated by phases II and III. It is believed, however, that it will be of benefit to the individual instructor, for with this information available he will be able not only to select the proper level of instructional material the class may absorb within the time permitted, but he will have the additional reserve information to answer questions with confidence, as they arise in the class.

Instructional material for phase II indoctrination also is covered in this publication. The chapter references for each phase III lecture are as follows:

Phase III	*Major reference*
1	Chapter 1, first portion; chapter 5.
2	Chapter 3.
3	Chapter 4.
4	Chapter 6.
5	Chapter 8.
6	Chapter 6.
7	Chapter 6.

CHAPTER 1

HISTORY OF ATOMIC ENERGY

Section I. DEVELOPMENT OF THE ATOM BOMB

The story of the atom bomb begins back in the middle ages when the alchemists attempted to change base metals into gold. It was not until 1896, however, that H. Becquerel accidently discovered the phenomenon of radioactivity by noting that uranium emitted invisible rays which affected a photographic plate. In 1898, the French scientists Marie and Pierre Curie discovered a number of elements, notably radium, which seemed to undergo a constant disintegration. The Curies explained this occurrence in terms of atomic decay. It was in 1905 that Albert Einstein defined the relation between all matter and energy and evolved his revolutionary theory of special relativity. Einstein concluded that the amount of energy, E, equivalent to a mass, m, was given by the equation $E = mc^2$ where c is the velocity of light. A number of years later in 1919 Lord Rutherford actually changed microscopic amounts of one element into another. This was the first man-made transmutation, and while it did not fulfill the dreams of the alchemists of changing base metals into gold, it did change the very stable gas, nitrogen, into the well-known, equally stable gas, oxygen. In 1932 Cockcroft and Walton verified, by experiment, the equation of Einstein for the equivalence of mass and energy.

The story of nuclear fission came to America in 1939. Shortly before Niels Bohr of Copenhagen, Denmark, arrived in the United States in January of that year to discuss certain abstract problems with Albert Einstein, his colleagues, O. R. Frisch and Lise Meitner, told him their guess that the absorption of a neutron by a uranium nucleus sometimes caused that nucleus to split into approximately equal parts with the release of enormous quantities of energy, a process that soon began to be called nuclear fission. The occasion for this hypothesis was the recent discovery of O. Hahn and F. Strassmann, in Germany, which proved that an isotope of barium was produced by neutron bombardment of uranium. Immediately on arrival in the United States, Bohr, communicated this idea to his former student, J. A. Wheeler, and to others at Princeton; from them the news spread to neighboring physicists, including E. Fermi at Columbia University. As a result of conversations between Fermi, J. R. Dunning, and G. B. Pegram, a search was undertaken at Columbia for the heavy pulses of ionization that would be expected from the flying fragments of the uranium nucleus.

On 26 January, 1939 there was a Conference on Theoretical Physics at Washington, D. C., sponsored jointly by the George Washington University and the Carnegie Institution of Washington. Fermi left New York to attend this meeting before the Columbia fission experiments had been tried. At the meeting Bohr and Fermi discussed the problem of fission and, in particular, Fermi mentioned the possibility that neutrons might be emitted during the process. Although this was only a guess, its implication of the possibility of a chain reaction was obvious. A number of sensational articles were published in the press on this subject. Before the meeting in Washington was over, several other experiments to confirm fission had been initiated, and positive experimental confirmation was reported from four laboratories (Columbia University, Carnegie Institution of Washington, Johns Hopkins University, and the University of California) in the *Physical Review,* 15 February, 1939. By this time Bohr had heard that similar experiments had been made in his laboratory in Copenhagen about January 15. (Letter by Frisch to *Nature,* 16 January, 1939, and appearing in the February 18 issue.) F. Joliot, in Paris, also had published his first results in the *Comptes Rendus,* 30 January, 1939. From this time on there was a steady flow of papers on the subject of fission, so that by 6 December, 1939 when Turner wrote a review article on the subject in the *Review of Modern Physics,* nearly one hundred papers had appeared.

In the summer of 1939, Dr. Leo Szilard discussed with Einstein the results of the findings that he and Dr. Fermi had made under Dr. G. B. Pegram, and stressed the urgent need for action by the United

States government. Conscious of the disaster which inevitably would follow if Nazi Germany should be the first to succeed in releasing atomic energy, Dr. Einstein wrote a personal letter to the President. Within a few days, the historic Einstein letter was taken to Washington by a New York economist, Alexander Sachs. The letter immediately was brought to the attention of the President. Recognizing the critical significance of Einstein's message, President Roosevelt signed an order appointing the Director of the National Bureau of Standards, Dr. Lyman J. Briggs, as Chairman of the Special Advisory Committee on Uranium. After only one meeting, the Committee was able to report that an atomic bomb was a definite possibility. By the following year the entire United States program of uranium research had been placed under the supervision of Dr. Vannevar Bush, Director of the Office of Scientific Research and Development.

With Presidential backing for an all-out research program, contracts were let to a dozen laboratories for exhaustive studies of every method offering any hope of success. In September 1942, on recommendation of Dr. Bush, the U. S. Army Engineers' newly created Manhattan District, under Major General Leslie R. Groves, was assigned the task of expanding the laboratory experiments into huge industrial projects. Meanwhile, in a secret laboratory at the University of Chicago, Dr. Fermi and his assistants achieved the first controlled chain reaction in uranium fission. The path now was cleared for the practical application of atomic power to the Nation's war effort. At Oak Ridge, Tennessee; at Hanford, Washington; and at Los Alamos, New Mexico, mammoth plants were built for the production of fissionable materials and atomic bombs. These establishments were staffed by thousands of able young scientists and technicians. Virtually exiled from the outside world, new communities sprang up almost overnight, as top priority materials and manpower were made available for the secret project. Mobilized to carry out the most formidable engineering job in ths history were thousands of the nation's industrial firms of every size and type. To keep the most closely guarded secret of the war, technicians and, even scientists, were strictly limited to knowledge of the specific tasks to which they were assigned.

Finally, after three years and an expenditure of two billion dollars, the atomic experts tested their first bomb on 16 July, 1945 at the Alamogordo Army Air Base in New Mexico.

Section II. THE ATOMIC ENERGY ACT AND ITS IMPLEMENTATION

Public Law 585—79th Congress (The Atomic Energy Act of 1946), an act for the development and control of atomic energy, was enacted for the purpose of producing fissionable material, developing atomic weapons, and utilizing atomic energy toward improving public welfare, increasing the standard of living, strengthening free competition in private enterprise, and promoting world peace. To accomplish this purpose, the Atomic Energy Commission was established. The relationship of the AEC to national Government is indicated in Figure 1.

All phases of the work on atomic energy, including procurement of raw materials, processing, bomb and isotope production, and research on atomic power plants, are under the control of the Atomic Energy Commission. While private companies and various universities are under contract to this commission for specific research and development projects, the commission has the exclusive right to own and produce all fissionable materials and atomic weapons.

The Atomic Energy Commission itself is composed of five members, including a chairman, all appointed by the President and approved by the Senate. However, it works in conjunction with a number of committees in order to get the most competent political, military, and legal advice possible. These committees include the Joint Committee on Atomic Energy, the Military Liaison Committee, the General Advisory Committee, and a number of other advisory committees. The Joint Committee on Atomic Energy represents Congress and consists of nine senators and nine representatives. The Military Liaison Committee consists of Army, Navy, and Air Force officers, under a civilian chairman, and is the channel of communication between the Atomic Energy Commission and the services. The General Advisory Committee is the top scientific advisory body through which outstanding scientists help the commission plan its work. The organization of the Atomic Energy Commission is shown in figure 2.

The AEC has four main objectives—

To produce fissionable material.

To develop better weapons for the defense of the country.

ORGANIZATION FOR MILITARY APPLICATION OF ATOMIC ENERGY

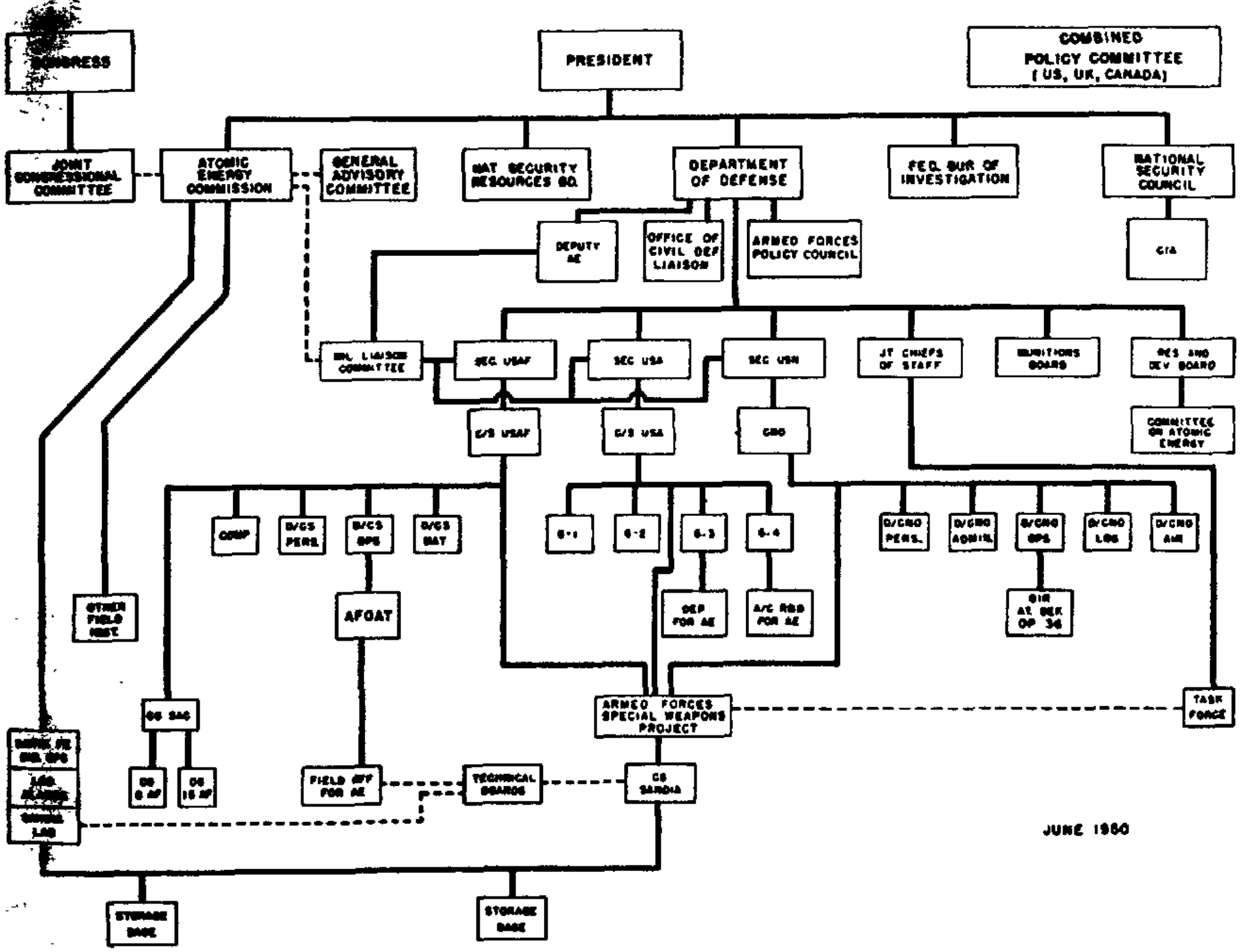


Figure 1.

To develop possible peacetime uses of atomic energy.

To develop such scientific strength in the country as is necessary to support the first two objectives.

To attain the first of its objectives the AEC operates a plant at Hanford to produce plutonium and a plant at Oak Ridge to separate uranium 235 from uranium 238. To attain the second objective it operates the Los Alamos and Sandia Laboratories. As an aid in attaining the remaining objectives, the AEC also operates five principal research laboratories—Argonne, Brookhaven, Clinton, Knolls, and Los Alamos.

The Los Alamos Scientific Laboratory, 35 miles from Santa Fe, N. M., was set up during World War II, specifically for the final development and improvement of atomic bombs. It performs additional duties relative to peacetime operations, such as fundamental research in nuclear physics.

The Argonne National Laboratory in Chicago also grew out of a war laboratory. It is conducted by the University of Chicago with the cooperation and participation of 27 other colleges and universities. Argonne is the center of the commission's reactor (atomic pile) development program and all the research and development connected with it.

The Clinton Laboratory at Oak Ridge, Tennessee started as a service and research laboratory in connection with the first atomic pile. It is the center for research done for the commission in chemistry, chemical engineering, physics, metallurgy and biology. Biological research has been built up largely since World War II to the point that Oak Ridge probably leads the world in this type of research.

Brookhaven Laboratory at Patchogue, Long Island, N. Y., has a different origin from the others.

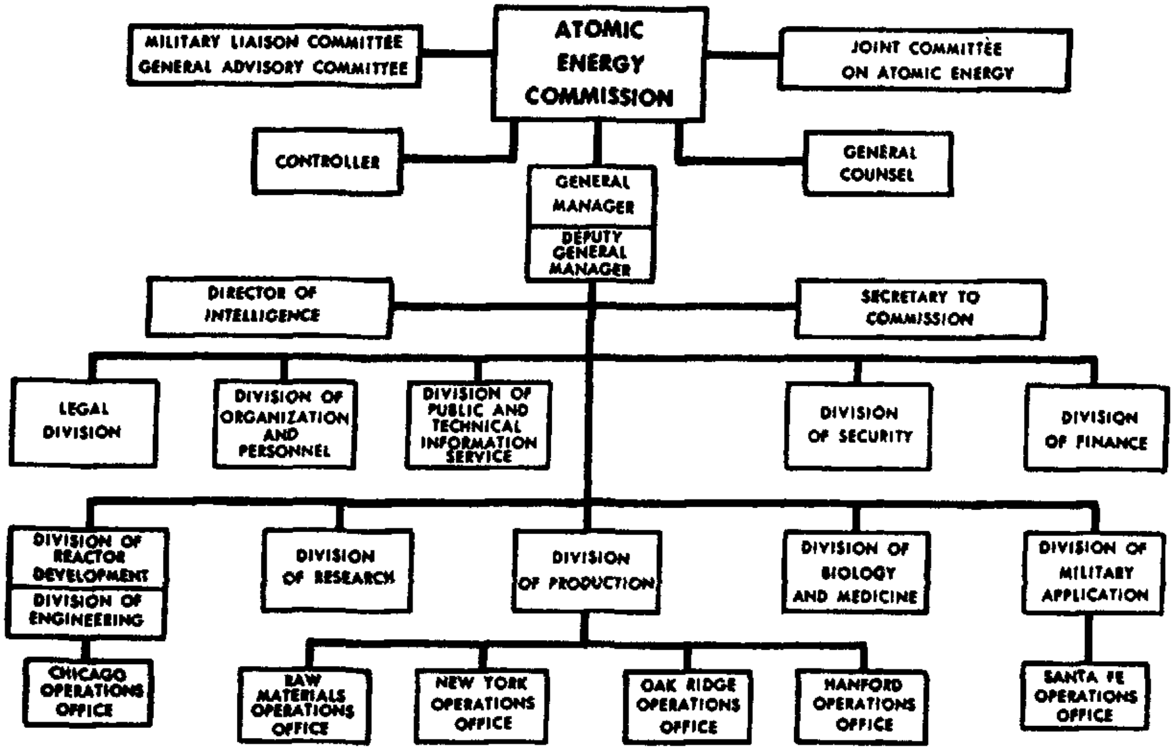


Figure. 2. Organization of the Atomic Energy Commission.

It was founded during World War II and began operating shortly thereafter. Brookhaven is operated by nine universities in the northeastern states and is a general laboratory for advanced work in the atomic energy aspects of physics, chemistry, biology, and medicine.

The Knolls Atomic Power Laboratory, Schenectady, N. Y., founded since World War II, is concerned especially with power and "breeding" applications. It is operated for the commission by the Research Laboratory of the General Electric Company. Scientific groups from various industrial organizations participate in the research work of the laboratory.

Other major research centers aiding the AEC are—

- Ames Laboratory, Ames, Iowa, operated by Iowa State College.
- Rochester Atomic Energy Project, Rochester, N. Y., operated by Rochester University.
- Westinghouse Co., Atomic Power Division, Pittsburgh, Pa., (complete construction is expected during 1950).
- Y-12 Research Laboratory, Oak Ridge, Tenn., an electromagnetic separation plant operated by Carbide and Chemicals Corporation.

Among the various committees working with the AEC, the Military Liaison Committee is of particular interest. It was established to serve as liaison between the Atomic Energy Commission and the Department of Defense. It is the responsibility of the Military Liaison Committee to keep the Department of Defense informed of any development in atomic energy that might be useful to it, and to keep the Atomic Energy Commission informed of the needs of the military services. The committee consults directly with any individuals or organizations of the Department of Defense, the Atomic Energy Commission, and all other departments or agencies of the Government, to exchange any information on atomic energy that is of military importance. It surveys, in conjunction with other military organizations, the over-all requirements of the Nation in the event of an emergency involving atomic warfare. The committee does not direct or control other organizations; it coordinates, surveys, and advises as a representative of the Secretary of Defense. The position of the Military Liaison Committee within the Department of Defense is illustrated in figure 1.

The Armed Forces Special Weapons Project was established to utilize, for the military, the information received from the AEC through the Military

ORGANIZATIONAL CHART OF ARMED FORCES SPECIAL WEAPONS PROJECT

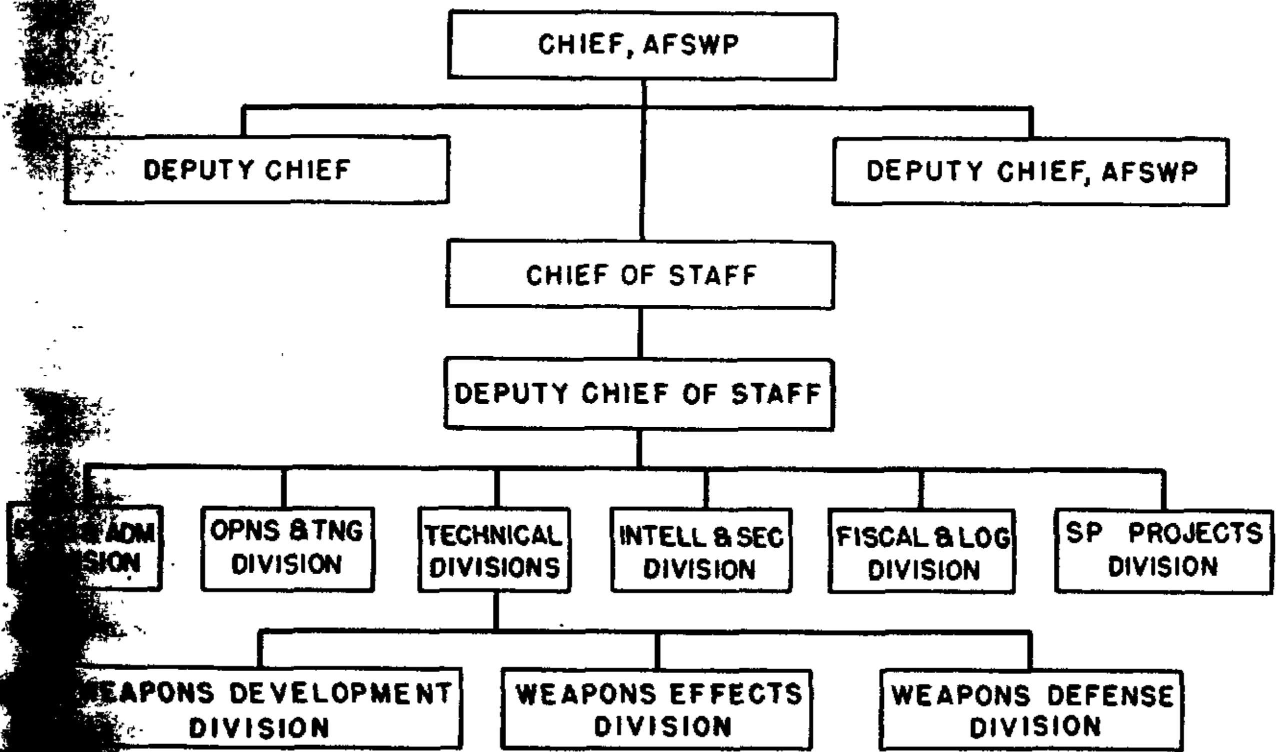


Figure 3.

ommittee. AFSWP has the responsibility ilitary service functions of the Manhattan retained under the control of the Armed including—

Training of special personnel.

Military participation in the development of atomic weapons of all types (in coordination with the Commission).

Technical training of bomb commanders and weaponeers.

Developing and effecting joint radiological safety measures in coordination with ablished agencies.

nishes assistance to the commandants schools, through appropriate channels, in preparing courses and training instructions, and collaborates in the preparation of atomic energy instructional material within the Army, the Navy, and the Air Force. It also furnishes material to responsible governmental agencies to assist in the education of the public on the military uses of atomic weapons, particularly, in connection with civil defense measures. Figure 3 shows the organization of AFSWP.

Within the Department of the Army, the Assistant Chief of Staff, G–3, Operations; General Staff; and the Assistant Chief of Staff, G–4, Logistics, General Staff have sections cognizant of radiological defense. The Department of the Army plan for radiological defense is included as appendix V.

CHAPTER 2

ELEMENTARY ATOMIC AND NUCLEAR PHYSICS

Section I. ELEMENTARY ATOMIC STRUCTURE

About 400 B.C., a Greek philosopher named Democritus decided that all matter consisted of atoms. He reasoned that if you kept cutting a piece of matter in half, eventually you would come to a small indivisible particle that could never be made any smaller. This theory existed without significant change until John Dalton, an English chemist, expanded it and proved the existence of atoms in 1807. Dalton thought of atoms as small solid particles which were identical with all other atoms of the same element, but differed from the atoms of any other element. In 1911, Sir Ernest Rutherford put forward the theory that the atom consisted of an "impenetrable" nucleus surrounded by electrons. Professor Niels Bohr made the first real model of the hydrogen atom in 1913.

Bohr's model of the hydrogen atom shows a miniature solar system with a heavy nucleus or "sun" and one electron circling around it in an orbit (figure 4). The nucleus is very small, about one millionth of a millionth of an inch, and contains nearly all the mass or weight of the atom. The electron circles around the nucleus to make a circle, or ellipse, with a diameter of one hundredth of a millionth of an inch or 10,000 times the diameter of the nucleus. The electron weighs 1/1840th as much as the nucleus. The nucleus of the hydrogen (H) atom is called a proton and has one unit positive electric charge, while the outer electron has one unit negative electric charge. These charges exactly balance each other and the atom is neutral.

The next heavier element, helium (He), proved to have two electrons in its orbit and two protons in the nucleus. The two protons balance the electric charge of the two electrons and the atom is neutral. However, this atom weighs *four* times as much as the hydrogen atom. Scientists could not explain this by saying there are four protons in the helium nucleus as this would not result in a neutral atom, so they looked for and found an electrically neutral particle, the neutron, with the same mass as a proton. Thus the helium nucleus consists of two protons, and two neutral particles, or neutrons (figure 5). The weight or mass of the helium nucleus (or atom as we neglect the small weight of the electrons) is four times the weight of one pro-

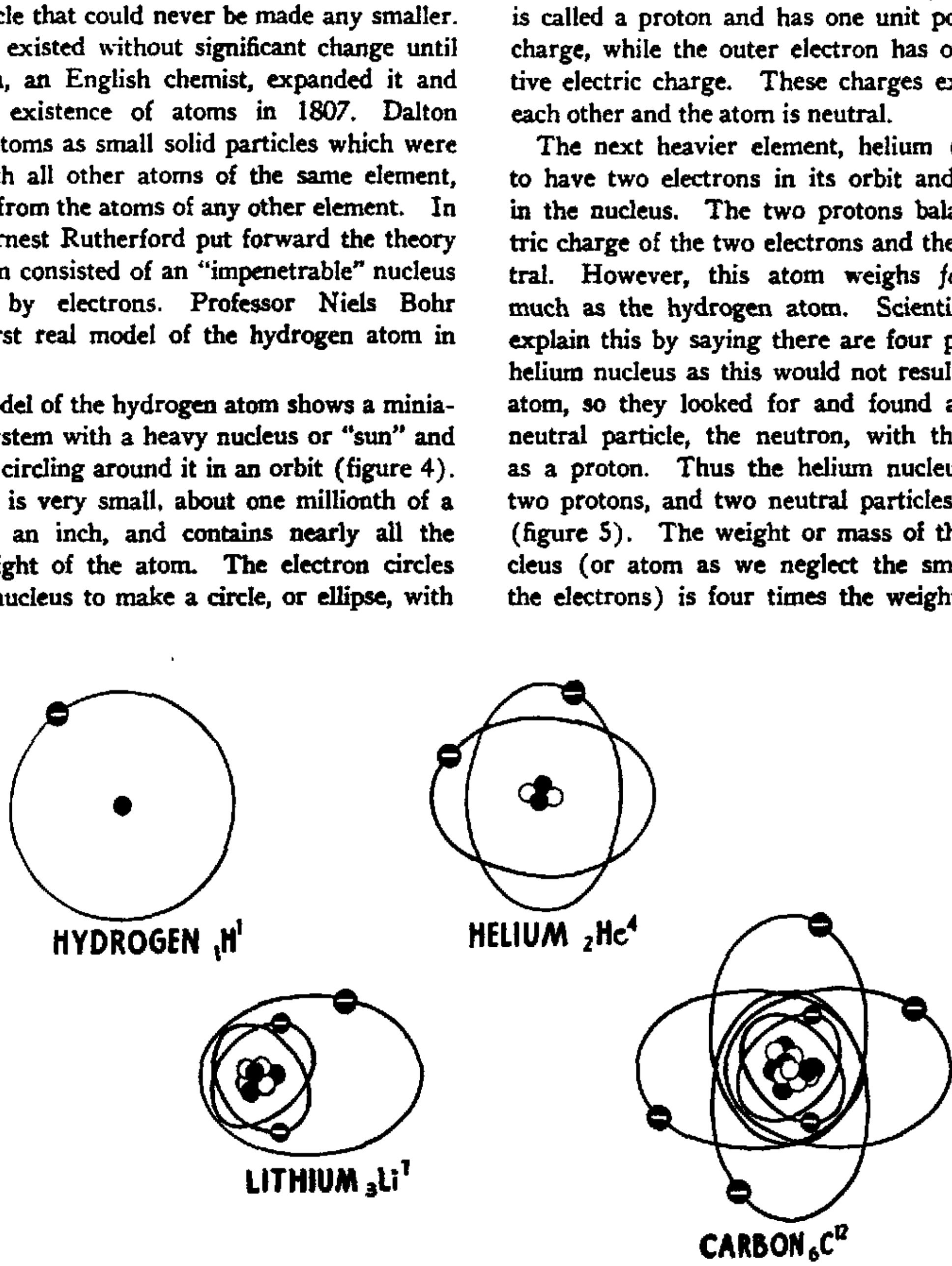


Figure 4. Graphical representation of structure of atoms.

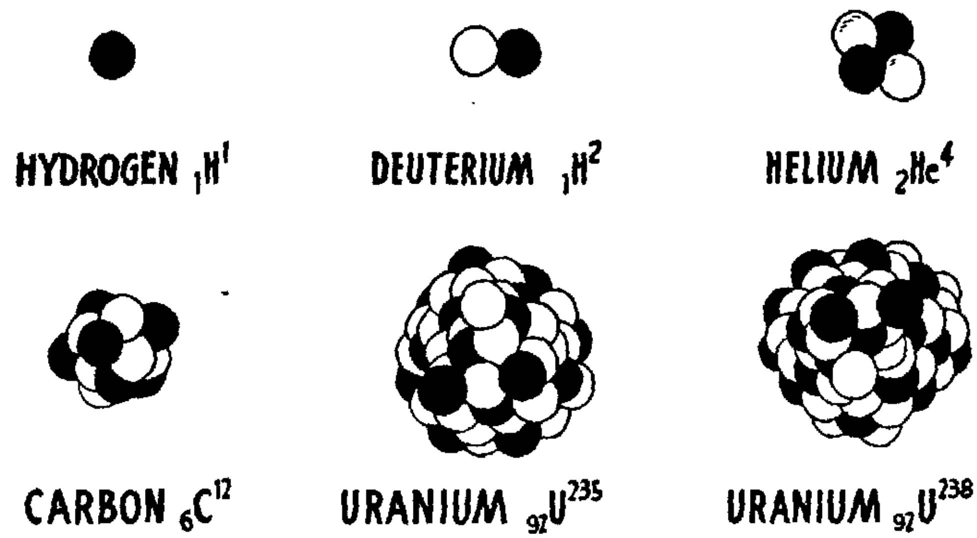


Figure 5. Graphical representation of the nuclei of atoms.

...ion, or is equal to four mass units. Protons and neutrons also are called nucleons, which means particles from the nucleus.

In this manner, atoms increase in size and com...y through carbon with 6 protons in the nucleus, ... with 8, iron with 26, uranium with 92, to ... element reported to have 97 protons. We ...e number of protons in the nucleus the ... number or Z number. The number of pro... etermines to which element the atom belongs. ...ny atom with 6 protons is an atom of car... ne with 26 is always iron, etc. The weight ... of an atom is equal to the total number ...trons and protons in the nucleus as each ... or proton weighs 1 m.u. (mass unit). This ...mber is called the mass or A number. For an ... of element X, the A and Z numbers are writ... follows: $_ZX^A$. Thus hydrogen is written as ...nifying 1 proton in the necleus for Z equal ... 1 particle in the nucleus for A equal to 1; ... is $_2He^4$ for 2 protons and 4 total particles ...ucleons); oxygen, $_8O^{16}$ for 8 protons and 16 ...rticles; etc.

...arizing the statements of the chapter so far, ... (except $_1H^1$) consist of protons and neu... the nucleus, with electrons circling around ... in orbits. There are the same number ...rons as protons and the atom is electrically

...re two further concepts of atomic struc... will be of assistance in understanding ...tions—ions and isotopes. An ion is an ... charged atom. Imagine something happening near a helium atom that knocks one electron completely out of the picture. The remaining "atom" has 2 protons or plus charges, and only 1 electron or negative charge. Therefore, the net charge on the ion is plus one.

An isotope is one of two or more forms of an element having the same atomic number (nuclear charge) and hence occupying the same position in the periodic table. All isotopes are identical in chemical behavior, but are distinguishable by small differences in atomic weight.

Normal helium $_2He^4$ and has 2 protons and 2 neutrons in its nucleus with an A number of four. Recall that the number of protons in the nucleus determines the element to which the atom belongs. An atom with two protons, *one* neutron and two electrons would still be helium, but its A number would be three. This atom exists and is called an isotope of helium, $_2He^3$. Normal uranium is a mixture of three isotopes, $_{92}U^{238}$ (99.3%), $_{92}U^{235}$ (0.7%) and $_{92}U^{234}$ (0.005%). One of the bomb materials used is $_{92}U^{235}$ the isotope with 92 protons and 143 neutrons in its nucleus and thus having a nucleon number of 235. Uranium also has isotopes $_{92}U^{228}$, $_{92}U^{229}$, $_{92}U^{230}$, $_{92}U^{231}$, $_{92}U^{232}$, $_{92}U^{233}$, $_{92}U^{237}$, and $_{92}U^{239}$, with 136, 137, 138, 139, 140, 141, 145, and 147 neutrons, respectively, none of which occur naturally, but all of which have been produced artificially.

Mendeleev, a Russian scientist, arranged the known elements by weight in the 1860's. He noted similarities in certain elements which seemed to repeat themselves at regular intervals or periods in the table. From these data he assembled his Periodic Table (figure 6). This table which is of great value to chemists has been used to predict the existence and characteristics of unknown elements, and provides a handy table of the elements for everyday use. Note that the atomic number is the Z number, but that the mass number shown below the symbol of the element is a proportional average of the isotopes existing in nature. As an example, if an element existed in nature with 75 per cent of its atoms of mass 4 and 25 per cent ions of mass 3, Mendeleev would show a mass of 3.75 as an average or apparent weight.

It is of interest to note that ordinary reactions, including conventional explosives such as TNT, involve only the orbital electrons and do not affect the nucleus of the atom whatsoever. Nuclear reactions, on the other hand, involve changes in the protons and neutrons in the nucleus of the atom. A spontaneous atomic disintegration is caused in which a relatively great amount of energy is liberated; and the process is accompanied by the emission of one or more types of radiation, such as alpha, beta, or gamma rays. Elements which emit one or more of these types of radiation spontaneously are called naturally radioactive elements. Since 1919 man has learned to produce them artificially, and these are called artificial radioisotopes.

Section II. NUCLEAR PHYSICS

Henri Becquerel, a French physicist, first observed natural radioactivity in 1896 while experimenting with a sample of uranyl sulfate. He noted that a metallic disk placed between a sheet a photographic film and a sample of the uranium salt was, in effect, "photographed" on the film, despite the fact that both the film and the uranium salt were enclosed in heavy black paper. This could be explained only by the existence of some penetrating radiation in the uranyl sulfate, and further experiment soon indicated that the radiation came from the *uranium* component of the salt.

Further study by Becquerel, Joliot and Curie, and others soon showed that there were three distinctly different types of radiation emanating from naturally radioactive elements such as uranium, radium, and protactinium. When studied in an electric field, as shown in figure 7, one type of radiation was deflected toward the positive pole. This radiation was named beta radiation (β), or beta particles, and eventually was identified as high-speed electrons. As the strength of the electric field was increased, a lesser deflection of one of the radiations toward the negative pole was noted. This radiation was named alpha radiation (α), or alpha particles. Inasmuch as the alpha radiation was deflected less than the beta, it was assumed to be a heavier particle than the beta. This was confirmed later when the alpha was identified as the nucleus of the helium atom, ${}_2He^4$. In other words, an alpha particle is a tightly bound group of two neutrons and two protons, with a mass of 4.002764 physical mass units and a net electrostatic charge of $+2$. The alpha particle is known to be a very compact and stable entity which does not itself disintegrate into transmutation reactions.

The third type of radiation, designated as gamma rays (γ), was found to be unaffected by the presence of an electric field, and was observed to be the most penetrating radiation of the three. Further study showed that gamma rays, unlike alpha and beta radiations, were not particles, but were electromagnetic waves of higher frequency than X-rays. Gamma radiations are emitted in homogeneous packets of energy known as photons, or quanta, and are electrically neutral.

Radioactive substances emit one or more of the above types of radiation by a process known as radioactive decay. In the case of gamma radiation only, no change in the number of protons or neutrons is involved. An atom which is in an excited state of vibrations may emit a gamma photon and drop to a lower energy level but, chemically, it remains the same atom. Using a shorthand system of designating atomic Z numbers at the lower left, and nucleon A numbers at the upper right, the following example of gamma photon emission may be cited:

$$ {}_{[illegible]}\mathrm{Np}^{[illegible]} \longrightarrow {}_{[illegible]}\mathrm{Np}^{[illegible]} + \gamma $$

stable atom

excited atom at a high energy level

In the case of the other two types of radiation, however, a new chemical element is produced. When an alpha particle is emitted from a radioactive nucleus, a new atom is formed whose Z number is two less than that of the original and whose

PERIODIC CHART OF THE ATOMS

Periods		*The Atoms Grouped According to the Number of Outer (Valence) Electrons* I	II	III	IV	V	VI	VII	VIII	Planetary Electrons in the Completed Shells: Total Atom No.	2(1² 2² 3² 4² 4² 3² 2²) K L M N O P Q	Periods
1	0 n 1.0086	1 H 1.0080							2 He 4.00	2 – End of the 1st period	2	1
2	2 He	Li 3 6.94	4 Be 9.02	5 B 10.82	6 C 12.01	7 N 14.01	8 O 16.000	9 F 19.00	10 Ne 20.18	10 = End of the 2nd period	2 8	2
3	10 Ne	Na 11 23.00	12 Mg 24.32	13 Al 26.97	14 Si 28.06	15 P 30.98	16 S 32.06	17 Cl 35.46	18 A 39.94	18 = End of the 3rd period	2 8 8	3
4	18 A	K 19 39.07	Ca 20 40.08	Sc 21 45.10	Ti 22 47.90	V 23 50.95	Cr 24 52.01	Mn 25 54.93	26 Fe 55.85	27 Co 58.94	28 Ni 58.69	4
		29 Cu 63.57	30 Zn 65.38	31 Ga 69.72	32 Ge 72.60	33 As 74.91	34 Se 78.96	35 Br 79.92	36 Kr 83.7	36 = End of the 4th period	2 8 18 8	
5	36 Kr	Rb 37 85.48	Sr 38 87.63	Y 39 88.92	Zr 40 91.22	Cb 41 92.91	Mo 42 95.95	Tc 43 99.	44 Ru 101.7	45 Rh 102.91	46 Pd 106.7	5
		47 Ag 107.88	48 Cd 112.41	49 In 114.76	50 Sn 118.70	51 Sb 121.76	52 Te 127.61	53 I 126.92	54 Xe 131.3	54 = End of the 5th period	2 8 18 18 8	
6	54 Xe	Cs 55 132.91	Ba 56 137.36	La 57 * 138.92	Hf 72 178.6	Ta 73 180.88	W 74 183.92	Re 75 186.31	76 Os 190.2	77 Ir 193.1	78 Pt 195.23	6
		79 Au 197.2	80 Hg 200.61	81 Tl 204.39	82 Pb 207.21	83 Bi 209.00	84 Po 210.	85 At 211.	86 Rn 222.	86 End of the 6th period	2 8 18 32 18 8	
7	86 Rn	Fa 87 223.	Ra 88 226.05	Ac 89 ** 227.05								7

6 *	58-71 Rare Earths Type 4f	58 Ce 140.13	59 Pr 140.92	60 Nd 144.27	61 Pm 147.	62 Sm 150.43	63 Eu 152.0	64 Gd 156.9	65 Tb 159.2	66 Dy 162.46	67 Ho 164.94	68 Er 167.2	69 Tm 169.4	70 Yb 173.04	71 Lu 174.99
7 **	90-103 Rare Earths Type 5f	90 Th 232.12	91 Pa 231.	92 U 238.07	93 Np 237.	94 Pu 239.	95 Am 241.	96 Cm 242.	97	98	99	100	101	102	103

Prepared by Illustration Branch Chemical Corps School from a chart designed by Henry D Hubbard (Deceased) National Bureau of Standards

Figure 6.

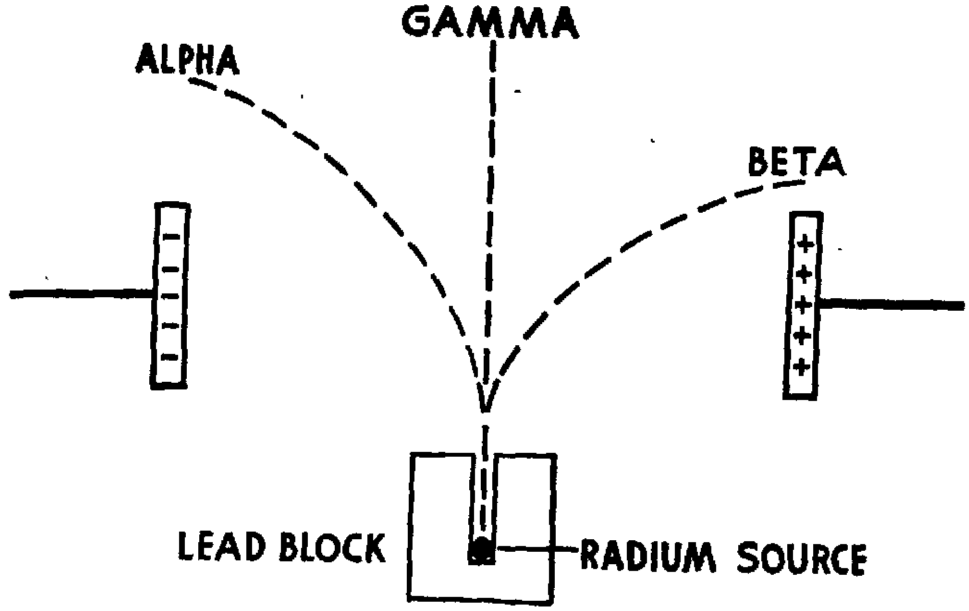


Figure 7. Separation of the emanations from a radium source by an electric field.

A number is four less than that of the original. For example:

$$_{91}Pa^{231} \longrightarrow {}_{89}Ac^{227} + {}_{2}He^{4}$$

Note that the sum of the A numbers on the right side of the equation (227 + 4) must equal the A number on the left side of the equation (231). Similarly, the sum of the Z numbers on the right side of the equation (89 + 2) must equal the Z number on the left side of the equation (91).

In the case of beta emission, there is no change in the A number (the rest mass of an electron is only about 1/1840th that of a nucleon), but the ejection of a beta particle from the nucleus will increase the nuclear charge by one unit positive charge, resulting in a Z number one greater than that of the original. For example:

$$\underset{\text{radioactive}}{_{79}Au^{198}} \longrightarrow \underset{\text{stable}}{_{80}Hg^{198}} + {}_{-1}\beta^{0}$$

It again is evident that the Z and A numbers on both sides of the equation balance.

It has been shown that naturally radioactive elements decay by the emission of alpha, beta, and gamma radiations. All of the radioactive elements known in the three radioactive series (uranium-radium series, thorium series, and actinium series) decay to some stable isotope of lead.

The decay of $_{92}U^{238}$ may be taken as an example. It is an alpha emitter and will decay to $_{90}Th^{234}$, which is also radioactive and will decay to $_{91}Pa^{234}$ by beta emission. This isotope is a beta emitter and decays in turn to $_{92}U^{234}$, which also emits an alpha particle and becomes $_{90}Th^{230}$. The stable product reached by tracing out the rest of the decay process will be the isotope $_{82}Pb^{206}$.

Early in the study of nuclear radiations it was discovered that the activity of a radioactive element decreased with time, and the time rate of decrease is measured in terms of the half-life (T) of the radioactive material. As the name implies, the half-life is the period of time required for the activity of an element to be reduced by 50 per cent. The half-life of any radioisotope can be determined only from a statistical study, that is, from a study of many billions of atoms; the half-lives of the different radioactive elements vary from a fraction of a second to many millions of years. For example, the isotope $_{55}Cs^{138}$ has a half-life of 33 minutes. Thus, if a large number of these atoms could be observed, it would be seen that one-half the initial number decay in 33 minutes, one-half the remaining number decay in the next 33 minutes, and so on. The following table illustrates how the activity of a radioactive element decreases with each half-life period:

Time in half-lives (T)	*Relative activity (Percent)*
O	100
T	50
2T	25
3T	12.5
4T	6.25

The production of an atomic, or nuclear, bomb is based on the fission of certain materials. After the discovery of the neutron in 1932 by the English physicist, Chadwick, scientists the world over began to bombard various elements with this newly discovered particle. Fermi, one of the early leaders in this work, bombarded uranium with slow or low energy neutrons and observed four new radioactive materials. He actually had observed the fission of uranium into elements of lesser atomic weight, but did not recognize them as such and falsely reasoned that he had produced transuranic elements, that is, elements of atomic number greater than 92. Curie and Joliet, in France; Lise Meitner, in Germany; and Hahn and Strassmann, in Germany; bombarded uranium, thorium, and protactinium with neutrons and also observed many radioactive products (most of which were beta emitters). Reasoning as Fermi did, they assumed that they had produced elements beyond uranium in the periodic table.

In *1939*, repeating their experiment, Hahn and Strassmann identified a barium isotope as a product of the uranium-neutron bombardment. The barium isotope was itself radioactive, emitting a beta particle to form radioactive lanthanum:

$$_{56}Ba^{140} \longrightarrow {}_{57}La^{140} + {}_{-1}\beta^{0}$$

Inasmuch as the lanthanum isotope also is a beta emitter, further decay to a stable isotope was to be expected:

$$_{57}La^{140} \longrightarrow {}_{58}Ce^{140} + {}_{-1}\beta^{0}$$

Basing their announcement on the results of these experiments, Hahn and Strassmann cautiously proposed a theory of nuclear fission; that is, the "splitting" of a heavy nucleus, such as U^{235}, into two or more nuclei of lighter elements. This information was communicated to Professor Niels Bohr, of the University of Copenhagen, at that time visiting the United States, and the German physicists' experiment was reproduced quickly at Columbia University, the University of California, Johns Hopkins University, and other places. Confirmation of fission was complete and physicists the world over instantly saw the possibility of a nuclear bomb.

In the study of nuclear fission it is important to understand exactly how fission takes place and by what mechanism a nucleus is transformed into two or more nuclei of lesser weight. Niels Bohr proposed an explanation based on elongation of the nucleus. It is to be remembered that the nucleus contains a definite number of protons and neutrons. Were there no neutrons in the nucleus, the nucleus would blow itself apart instantly, due to the coulomb forces of repulsion between the like-charged protons. Thus, the neutrons serve as a binder to hold the nucleus together by virtue of extremely powerful nuclear forces which operate at very short range. In order to induce fission, these short range, extremely powerful nuclear forces must be counterbalanced. Bohr's theory is that this is accomplished by elongation of the nucleus beyond the very short range in which these nuclear forces exist. The bombarding particle, in this case a neutron, enters the nucleus fairly easily (it is not repelled by the coulomb forces, as a proton, deuteron, or alpha particle would be) and instantly upsets the ration of neutrons to protons in that nucleus. This tends to promote a stretching or elongation of the nucleus as illustrated in figure 8. As this elongation begins, the protons repel each other and tend to congregate at the exterior of the nucleus, leaving the neutrons in the interior. As the distances increase due to the elongation of the nucleus, the nuclear forces are no longer so significant, but the coulomb forces of electrostatic repulsion are still quite strong. When the critical point is reached, the nucleus actually ruptures or splits, usually into two major fragments, sometimes into three, very rarely into four. In addition, surplus neutrons often are emitted. It is of great interest to note that the entire elongation-fission process takes place in a period of time usually measured in fractions of a microsecond.

The possibilities in fission of U^{235} are many. As a matter of fact, over 200 isotopes have been identified as fission products from the fission of U^{235}, some of them so unstable that their half-lives are of the order of magnitude of only a few microseconds (1 microseconds $= \dfrac{1}{1{,}000{,}000}$ of a second). To visualize the fission process, one may assume that a neutron entering the U^{235} nucleus forms, for an extremely short time, unstable U^{236}, which then splits, according to the Bohr mechanism described above. Some of the possibilities of products are—

$$
\begin{aligned}
{}_{92}U^{235} + {}_{0}n^{1} &\longrightarrow {}_{56}Ba^{140} + {}_{36}Kr^{94} + 2{}_{0}n^{1} + \Delta Q\\
{}_{92}U^{235} + {}_{0}n^{1} &\longrightarrow {}_{39}Y^{97} + {}_{53}I^{136} + 3{}_{0}n^{1} + \Delta Q\\
{}_{92}U^{235} + {}_{0}n^{1} &\longrightarrow {}_{46}Pd^{117} + {}_{46}Pd^{117} + 2{}_{0}n^{1} + \Delta Q\\
{}_{92}U^{235} + {}_{0}n^{1} &\longrightarrow {}_{54}Xe^{139} + {}_{38}Sr^{94} + 3{}_{0}n^{1} + \Delta Q
\end{aligned}
$$

Most of the fission products are themselves radioactive, with very short half-lives. By use of a table of isotopes, one may determine the final, stable end-products.

In each of the fission equations above, a net amount of energy, ΔQ, is released. By virtue of the Einstein relationship, it is known that matter may be con-

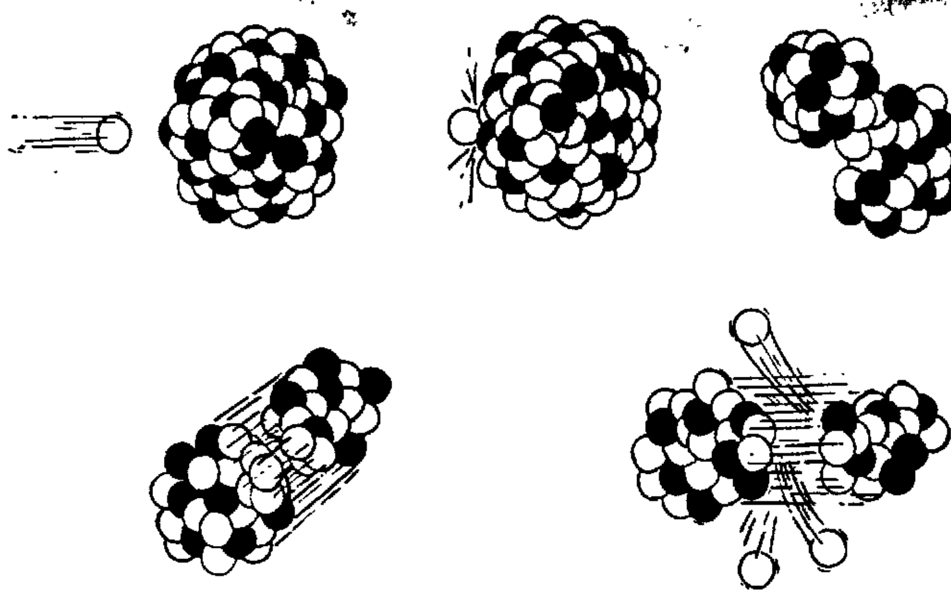


Figure 8. The fissioning of Uranium 235.

verted into energy (and vice versa). The magnitude of the conversion is indicated by the Einstein equation, $E = mc^2$, where E is energy, m is mass, and c is the velocity of light. If 1 gram of material is completely converted into energy, that quantity of energy is 9×10^{20} ergs. If it is assumed that this amount of energy were released in less than one one-millionth of a second (as in an atomic explosion), the power developed is of the order of magnitude of a hundred thousand million million horsepower! Careful measurements and calculations show that, in any fission, the total mass of the products is less than the total mass of the reactants (that is, the U^{235} nucleus and the bombarding neutron). This loss of mass can only be manifested by the release of an equivalent amount of energy. Experiment and calculation have shown that, while the amount of energy released will vary (depending on the products formed, the number of neutrons emitted, and so on), the average figure, per nucleus of U^{235} fissioned, is of the order of magnitude of 200 Mev (million electron volts). In comparison, the explosion of one molecule of TNT releases less than 25 ev (electron volts).

In the fission process free neutrons also are released, the number varying between one and four. The number is largely a matter of statistical probability but again, on the average, will be more than two neutrons per nucleus fissioned. This release of surplus neutrons makes it possible to build up a chain reaction wherein neutrons released in the fission of one nucleus go on to cause fission in other nuclei which, in turn, emit neutrons. In an atomic bomb burst this chain reaction, involving many billions of nuclei, takes place in a few microseconds, until the explosion blows the bomb material apart.

Each nucleus of U^{235} fissioned furnishes about 200 Mev of energy. However, fission does not take place spontaneously; a certain minimum amount of energy (approximately 5 Mev in the case of U^{235}) must be added before fissioning starts. This energy needed to overcome the so-called fission barrier is known as the activation energy or excitation energy. Since a very low energy (thermal) neutron will contribute about 7 Mev to a U^{235} nucleus, it is obvious that such a neutron can cause fission of the U^{235} nucleus. Activation energy may be compared to the extra push needed to move a large boulder from a 1-foot depression at the top of a high hill and cause it to roll down the slope. In its high position the boulder possesses potential energy, but before this energy can be realized as energy of motion (kinetic energy), additional potential energy must be imparted to it to clear the top of the hill. This analogy (fig. 9) corresponds to the large amount (200 mev) of energy which will be released in the fission of a U^{235} nucleus, once the fission barrier (about 5 Mev) is cleared.

It has been stated that the energy released in nuclear reactions is the conversion of some of the mass into energy according to Einstein's mass-energy equation, $E = mc^2$. When the individual masses of the neutrons and protons that make up a nucleus are added together, their total is greater than the mass of the nucleus as a unit. This difference in mass is

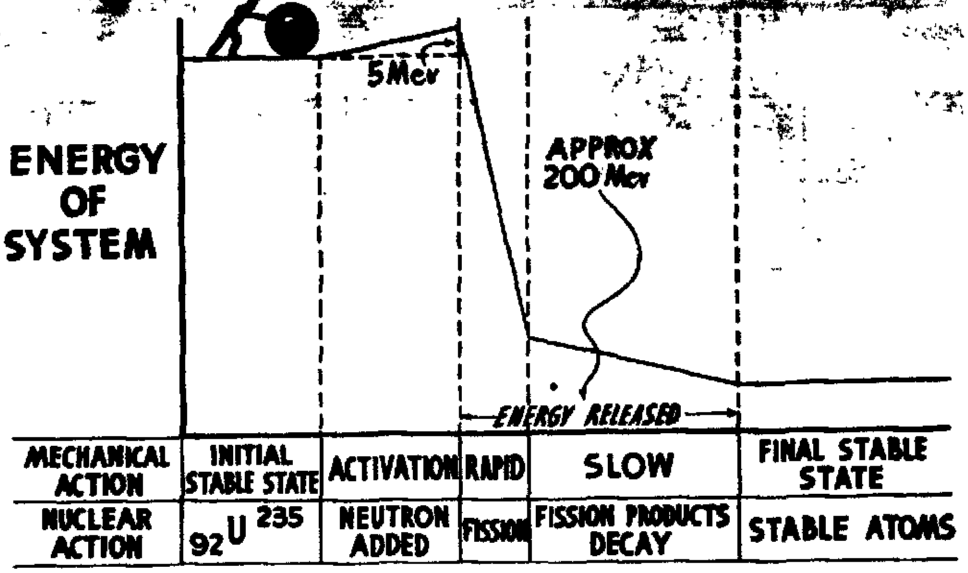


Figure 9. Mechanical analogy of nuclear fission.

characteristic of every nucleus containing more than *one nucleon.* The mass defect, when multiplied by 931 Mev/m.u. and divided by the A number, gives the BE/A (binding energy per nuclear particle).

If we plot on a graph the mass numbers of the elements against the BE/A for each element, we get a mass vs. stability curve (figure 10). This curve reveals that the most stable isotopes (those whose BE/A is the greatest) occur in the vicinity of mass number 60. Elements whose A numbers are smaller or greater, have a smaller BE/A value and therefore, are theoretically less stable. Elements whose nucleon numbers are greater than 60 (for example, uranium), have less BE/A than elements of nucleon number around 60 (near nickel or zinc in the periodic table), so it is energetically possible for them to undergo fission, since they will be going from a higher energy level (where they are less stable) to a lower energy level (where they are more stable). As an example, in the fission of U^{236} into two symmetrical palladium fragments (a rare occurrence in fission products), we may examine the energy relationship—

$$_{92}U^{235} + {}_0n^1 \longrightarrow \underset{\text{highly unstable}}{_{92}U^{236}} \longrightarrow {}_{46}Pd^{118} + {}_{46}Pd^{118} + \Delta Q$$

BE/A of $_{92}U^{236}$ = approximately 7.5 Mev (calculated by formula)

BE/A of $_{46}Pd^{118}$ = approximately 8.5 Mev

Since two nuclei of Pd^{118} are formed for each nucleus of U^{236} fissioned, the net change in binding energy is—

$$118 \times 8.5 + 118 \times 8.5 - 236 \times 7.5 = 236 \text{ Mev}$$

This is in good agreement with the average figure of 200 Mev of energy per nucleus fissioned.

For elements below mass number 60 in the periodic table, the release of energy through fission is not possible, since such elements would be going from a lower energy level to a higher energy level. This is a possible phenomenon only by the addition of energy. Elements below this point can release energy only by fusion—that is, the coalescing of two atoms. For example, two atoms of heavy hydrogen, or deuterium, may fuse into a helium atom, a very stable configuration:

$$_1H^2 + {}_1H^2 \longrightarrow {}_2He^4 + \Delta Q$$

For this reaction the mass defect is:

$$2 \times \text{mass of } {}_1H^2 - \text{mass of } {}_2He^4 = 2 \times 2.014708 - 4.00390 \text{ m. u.}$$
$$= 4.029416 - 4.00390 \text{ m. u.}$$
$$= 0.025516 \text{ m. u.}$$

The energy released is approximately 24 Mev (0.025516 m.u. $\times$ 931 Mev/m.u.). This is considerably less than the 200 Mev released per nucleus of U^{235} but 24 Mev per 4 nucleons for He^4 is a much larger figure than 200 Mev per 236 nucleons for U^{235}. Gram for gram, much more energy will be available from the fusion of hydrogen than from the fission of uranium, provided all nuclei fuse or fission in the processes. The mass vs. stability curve shows that the drop from H^2 to He^4 is much steeper than the drop from U^{235} to such elements as Ba^{140}, Kr^{94}, I^{139}, Y^{95}, and Pd^{118}.

Thus, it will be seen that where heavier elements tend to go to a more stable state by undergoing fis-

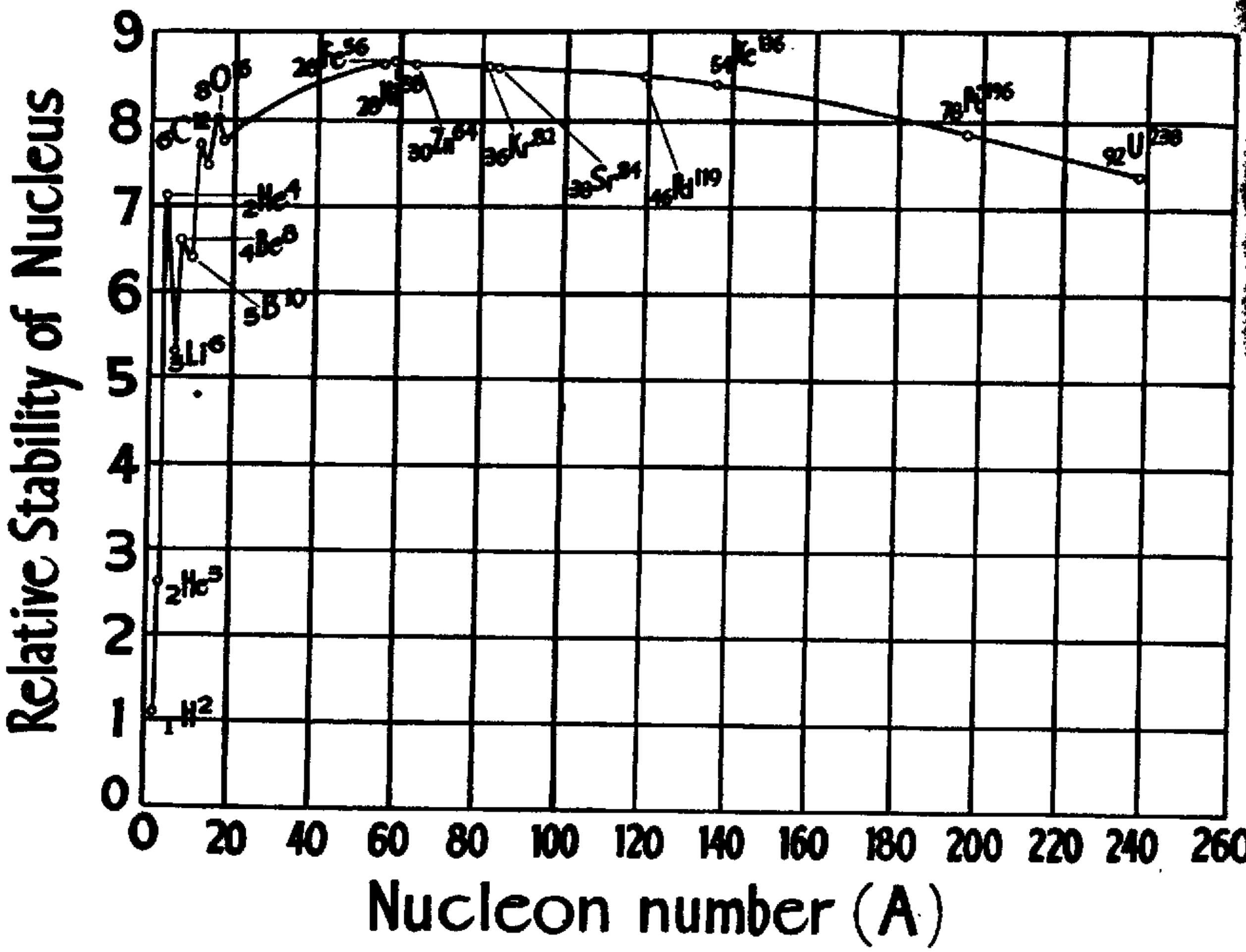


Figure 10. Nuclear stability of the elements.

sion, lighter elements tend to fuse into more stable nuclei. Energy is released in both cases since there is a loss of mass in each reaction. In the light elements, the attractive or nuclear forces are greater than the coulomb forces of repulsion. When these two forces are exactly balanced, the nucleus is extremely stable since there is no tendency to break into smaller parts due to repulsion, and there is no tendency to fuse together into larger parts due to "surface-tension" type of attraction. These dual conditions occur in the vicinity of Fe^{56} or Ni^{58} on the mass vs. stability curve. Theoretically, all nuclei eventually should stabilize themselves by forming an Fe or Ni (or possibly Zn) isotope. There are very good physical reasons why this does not actually take place at a measurable rate in nature. This stabilization would take place through fission or fusion, whichever is appropriate. The farther "up" an element is from Fe or Ni in the periodic table, the more unstable it is, and the more energy can be liberated by its fission. For example, 1 pound of Pu^{239} in which *all* nuclei fission will liberate more energy than 1 pound of U^{235} in which *all* nuclei fission.

Fission of various isotopes may be induced by particles other than neutrons. Protons, deuterons, and alpha particles may be used (although with much greater difficulty, because of the coulomb forces of repulsion on positively charged particles), and even cases of photon-fission are known, wherein fission is induced by a gamma photon. From the military point of view, however only three isotopes may presently be classified as fissionable materials: U^{233}, U^{235}, and Pu^{239}. The cross section of the nuclei of these materials is such that the materials will undergo fission by neutrons and hence may be used in atomic explosives. Different materials will yield different fission products, but virtually all fission products identified to date lie between the extreme of Zn^{72} and Gd^{160}.

The factor which apparently determines the relative stability of an isotope is its n/p (neutron-proton) ratio. With few exceptions, elements whose n/p ratio is considerably higher than *about* 1.3 are unstable. U^{235} has 143 neutrons and 92 protons and an n/p ratio of 143/92 or 1.55. Assuming that the end-products of a fission reaction are Br^{87} and La^{146} (plus extra neutrons), it can be shown that the n/p ratio is related to stability. Bromine has only two stable isotopes, those of mass numbers 79 and 81, whose n/p ratios are *1.26 and 1.31, respectively.* But Br^{87} is a known fission product—it has been identified. It has, therefore, six excess neutrons and it is therefore radioactive (that is, unstable). It will reach stability by beta emission which will tend to reduce the n/p ratio. The following is the decay process of Br^{87}:

$$_{35}Br^{87} \xrightarrow[\text{emits } \beta]{} {_{36}Kr^{87}} \xrightarrow[\text{emits } \beta]{} {_{37}Rb^{87}} \xrightarrow[\text{emits } \beta]{} {_{38}Sr^{87}}$$

stable

It will be noted that beta emission tends to reduce the n/p ratio in a double manner, for it increases the denominator (protons) by one and simultaneously decreases the numerator (neutrons) by one. Beta emission is physically explained by the hypothesis that is a neutron is converted into a proton and a beta particle and the latter is then emitted.

Most fission products are radioactive but, occasionally, a stable isotope is formed directly from the fission reaction. An example is—

$$_0n^1 + {_{92}U^{235}} \longrightarrow {_{54}Xe^{136}} + {_{38}Sr^{97}} + 3\,{_0n^1} + \Delta Q$$

In this case, the xenon isotope, despite its high n/p *ratio of 1.52, is stable.* (It is *one of the exceptions* referred to above.) The strontium isotope, however, with an n/p ratio of 1.55, is unstable and will decay to a stable isotope as follows:

$$_{38}Sr^{97} \xrightarrow[\text{emits } \beta]{} {_{39}Y^{97}} \xrightarrow[\text{emits } \beta]{} {_{40}Zr^{97}} \xrightarrow[\text{emits } \beta]{} {_{41}Nb^{97}} \xrightarrow[\text{emits } \beta]{} {_{42}Mo^{97}}$$

stable

The molybdenum isotope, with an n/p ratio of 1.31, is stable. If it possessed excess energy after fission, the Xe^{136} would reach stability by emission of one or more gamma photons with no change in either A or Z number.

As stated previously, the total energy released in the fission of one nucleus of fissionable material will vary according to the ratio of the masses of the product nuclei, but the average energy released is of the order of magnitude of 200 Mev. This quantity of energy, imparted largely as kinetic energy, will be distributed approximately as follows:

Fission product nuclei	160 Mev
Prompt neutrons	5 Mev
Prompt gamma photons	5 Mev
Radioactive decay series	20 Mev
Absorbed neutrons	10 Mev
Total	200 Mev

The "prompt" neutrons are emitted within 10^{-13} second after fission and should be distinguished from the "delayed" neutrons, which generally are emitted within 0.2 second after fission (although a very few may be delayed up to one minute). Delayed neutrons make up about 0.6 percent of the total number of neutrons emitted in a chain reaction, and of this number only about 1/30 are emitted later than 0.2 second after fission. For practical purposes only the 99.4 percent emitted within 10^{-13} second after fission are considered.

With regard to the fission yield, it is not possible to predict what fission products will occur from a given fission reaction. Even if conditions are identical, successive fissions will not necessarily (or even probably) give the same fission products. Fission yield is best discussed from the statistical point of view. After observing the fission products formed *from a great number of fissions, one may plot* on semilog paper the nucleon numbers of the products formed against the fission yield in percentage of each isotope formed, where fission yield is the percentage for fission isotope formed of the total number of atoms fissioned (fig. 11). The resulting curve for slow neutron-induced fission shows that the average mass values for the fission fragments are about 95 and 139. The probability for fragments of these nucleon numbers, from the curve, is about 1,000 times as likely as the probability that the nucleus fissioned will split into two symmetrical fragments.

Thus it can be seen that nuclear fission weapons provide for the rapid release of large amounts of energy, accompanied by the emission of great amounts of electromagnetic radiations, and particles such as alphas, betas, and neutrons.

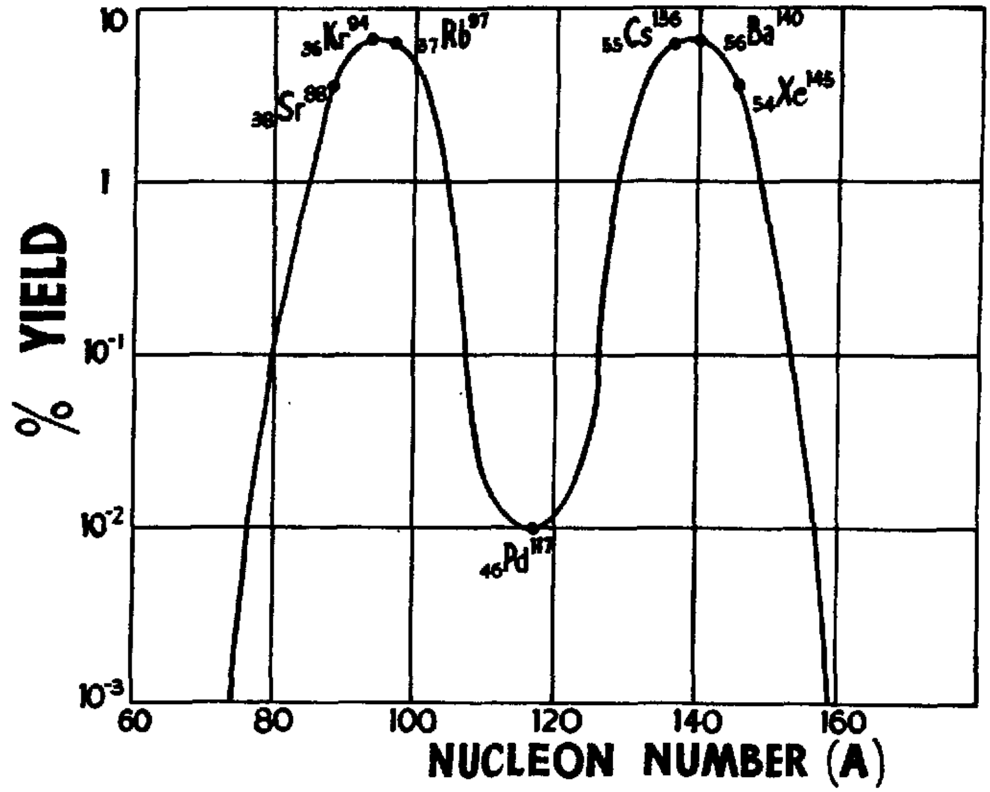


Figure 11. Probable distribution of fission products from U^{235}.

Section III. THE NUCLEAR REACTOR

The operation of a nuclear reactor or atomic pile, as it is commonly called, depends on the fact that a chain reaction is possible in the fission process with the release of large quantities of energy. If this chain reaction takes place in a certain amount of fissionable material within the short space of a few microseconds, a tremendous amount of energy is released and there will be an atomic explosion. On the other hand, if the reaction can be controlled to take place over a reasonable length of time, there will be a source of controllable energy. A nuclear reactor, then, is essentially a chain reacting system in which the energy from the fission of uranium or plutonium is released at a controlled and predetermined rate.

The fundamental fissioning process has been described in section II of this chapter. The fissionable material is, in effect, the fuel from which energy is derived and, as it is fissioned, it is used up and must be replenished from time to time. At the same time that fissionable material is being used up, many fission products are produced. These fission products are highly radioactive and considerable protection in the form of large concrete shielding must be provided to protect personnel. There also will be great neutron flux throughout the pile. It is this dense neutron flux which is used to make stable isotopes artificially radioactive. Hence, the atomic pile is a potential manufacturer of large quantities of radioactive isotopes by neutron irradiation as well as by the fission process.

Most of the energy released in the fission process appears in the form of kinetic energy of the fission fragments. It is this kinetic energy which, converted to heat, makes the atomic reactor a source of power.

In place of reaction time measured in microseconds and temperatures measured in millions of degrees, the power plant designer is interested in more nearly steady power conditions and temperatures no higher than normally are encountered in chemical reactions. This establishes the essential difference between the use of nuclear fission for the purposes of atomic bombs on the one hand and for the supply of energy on the other. It is again emphasized that the nuclear reactor is a source of heat energy developed by converting mass into energy. It is not a perpetual motion machine. Fuel is used up and must be replenished. In this case, the fuel is a fissionable material, either uranium or plutonium.

The neutrons released at the instant of the fissioning of the atom possess high kinetic energy of the order of one or more Mev. Inducing a large enough fraction of these neutrons to fission U^{235} to maintain the supply of neutrons (instead of being used up in converting U^{238} to plutonium) requires that some means be provided to reduce the high energy neutrons to low (thermal) neutrons before they can react with any uranium atoms. This is accomplished by placing a suitable material in the path of the neutrons in which they dissipate their energy while removed from the presence of uranium, by colliding with the material until they finally become low energy neutrons. The material used to dissipate the energy of the neutrons is called the moderator. The fastest means by which neutrons lose their energy is by collision with particles having about the same mass as the neutrons themselves. The moderating material therefore should be of approximately the same atomic mass as the neutron and hence would be confined to the very light atomic substances. Actually, there are a few materials that meet all the requirements for a usable moderator. Water, deuterium found in heavy water, and graphite are most commonly used as moderators.

Another important feature of any nuclear reactor pile is the control of its energy level. This control is accomplished by inserting into the active lattice work some material which will capture the neutrons and hence prevent them from producing further fission. Any material which has a large probability for the capture of neutrons is suitable. Two elements, boron and cadmium, have the desired characteristics to act as controls. These materials are made in the form of rods and arranged so that they can be moved in or out of the lattice work. Inserting these rods deeper into the lattice work reduces the neutron flux by capture and hence lowers the operating energy. Removing the rods increases the production of fissioning and hence the heat energy.

Since the energy released in a pile is the result of fission, the amount of energy released at the operating power level of the pile depends upon the number of fission processes occurring throughout the pile in a unit of time. This depends upon the neutron density. The operating level of a pile thus can be established by controlling the neutron density by the use of control rods.

Figure 12 shows a cut-away section of a basic nuclear reactor. The center consists of a lattice work in which is imbedded the fuel rods, surrounded by large quantities of the moderating material. Interspersed within the lattice work are the control rods which control the rate at which the pile operates. Provision must be made for some type of coolant, usually water, to circulate through the pile and remove the large amount of heat energy generated. Surrounding the lattice work usually included is a reflector which serves to reflect the great neutron flux back into the pile. Finally, around the entire pile is constructed a thick shield of concrete.

Approximately 80 percent of the energy of fission is released as kinetic energy of the fission fragment. This kinetic energy, in turn, is converted to heat as these recoiling fission fragments are stopped within the pile. The function of the coolant is to carry off this heat. In the case of a power reaction the heat is carried to a heat exchanger to be made availible for use as power.

The design of reactors depends upon their use. They may be operated at a high energy level or a low energy level. They may be for pure research or for the development of useful power. They may be designed to produce plutonium or large supplies of radioactive isotopes for research and other uses. Reactors may be classified in a number of ways—on the basis of the energy of a neutron flux within the pile, on the type of moderator used, on the type of coolant, and on the pattern of the lattice structure within the pile.

Inasmuch as there is a great development of radiation from the pile, much attention must be paid to the protection of personnel working around the reactor. This protection usually is provided by large thicknesses of concrete.

The size of the pile itself may vary from a relatively small sphere about one foot in diameter up to the size of a building, depending somewhat upon its shape, the type of fissionable material used, the purity of the fissionable material, and the operating energy level of the pile. The use of a reflector helps to reduce the size of a pile as far as the active material is concerned. The geometrical shape of the pile generally is some simple form in which the three principal dimensions are approximately equal. It may be in the form of a sphere, a cube, a rectangular cylinder, or even a prism. The active section of the pile may be a homogeneous mixture of its components, or these may be arranged in a heterogeneous pattern, in

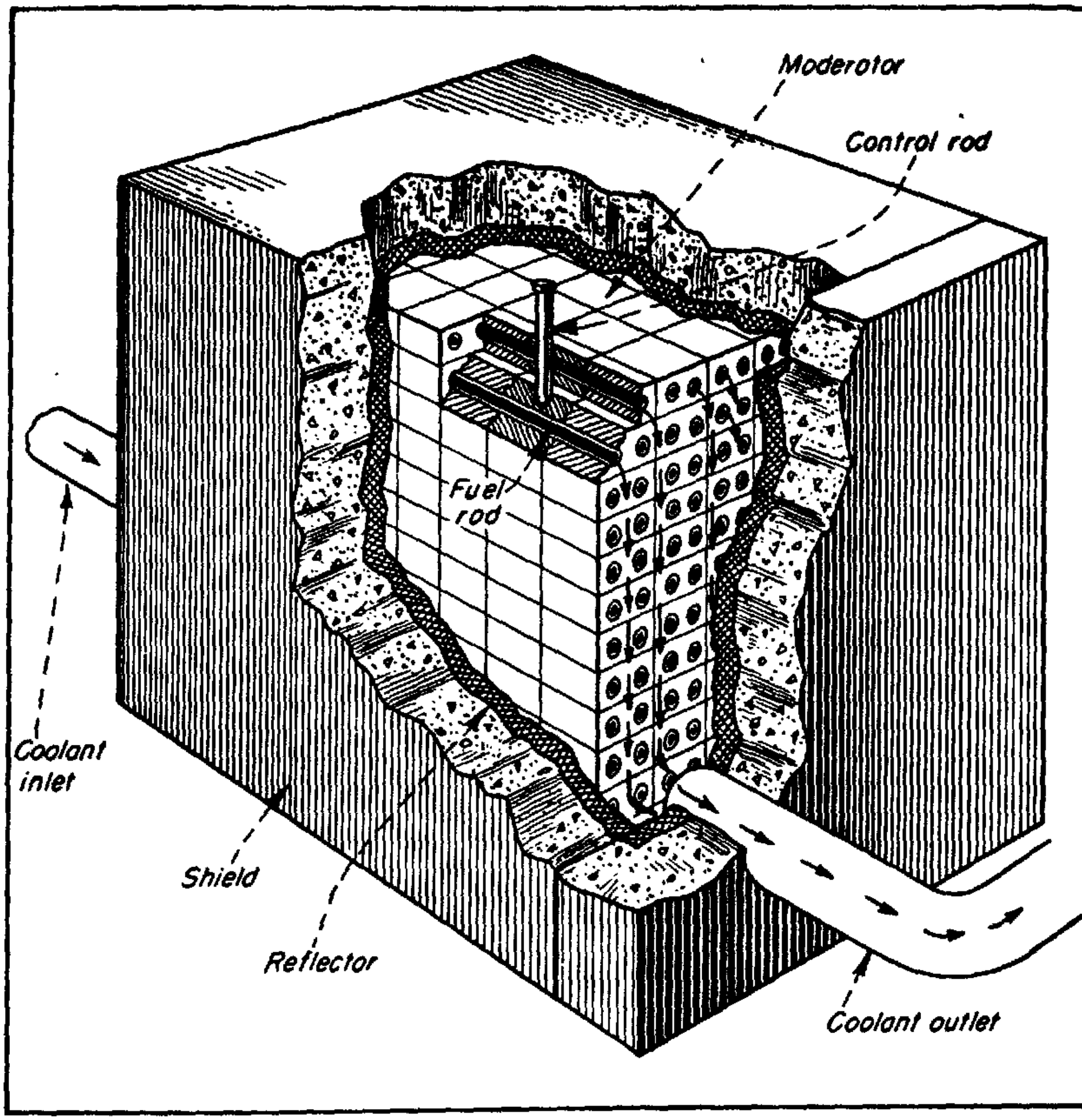
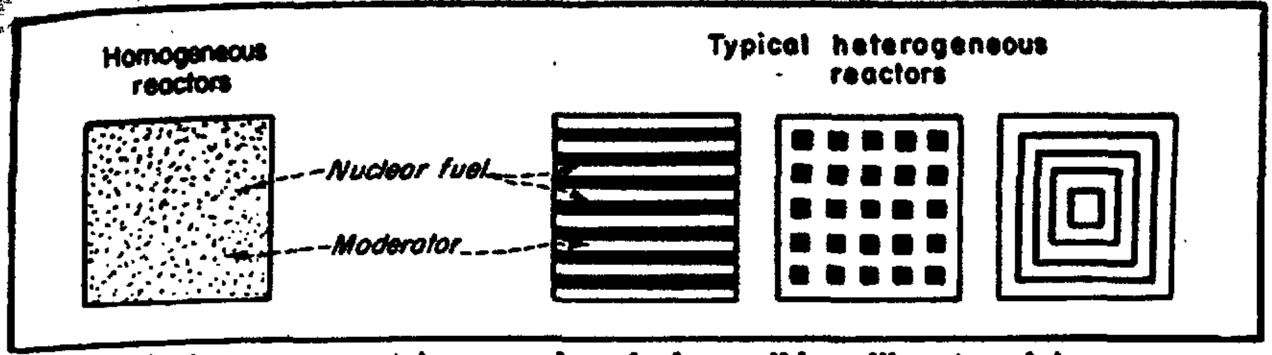


Figure 12. A basic nuclear reactor.

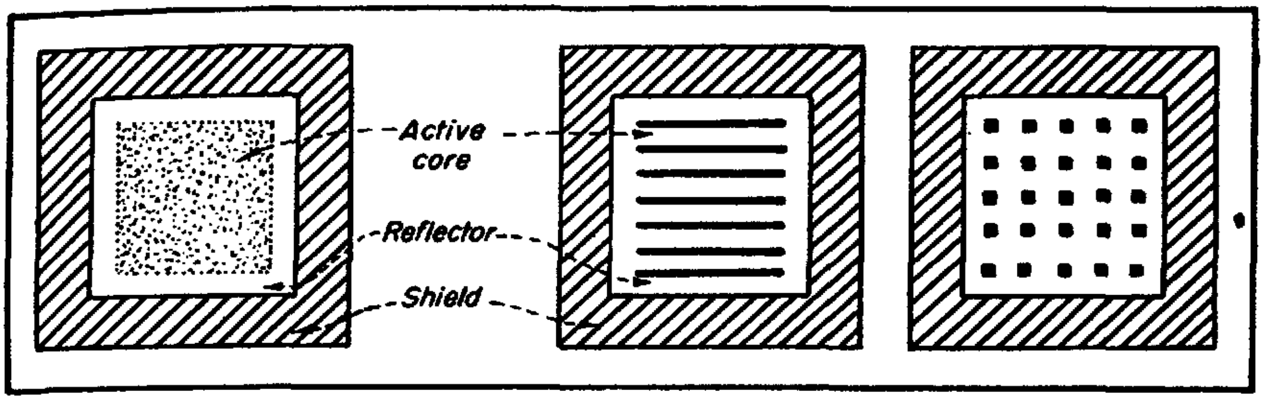
which the components are placed geometrically in a lattice network (fig. 13). Considerable research and design engineering presently are being carried out to determine the most efficient manner of building these sources of nuclear energy. Five non-production atomic piles are in operation in the United States today with a sixth soon to be in operation. These atomic piles are listed in table I.

Other factors affecting the size of the pile are the kind of fissionable material or nuclear fuel and the form and availability of the fuel. While many different materials can be fissioned under the proper conditions, there are at present, only three practical nuclear fuels, only one of which occurs in nature. These three fuels are U^{235}, U^{233} and Pu^{239}.

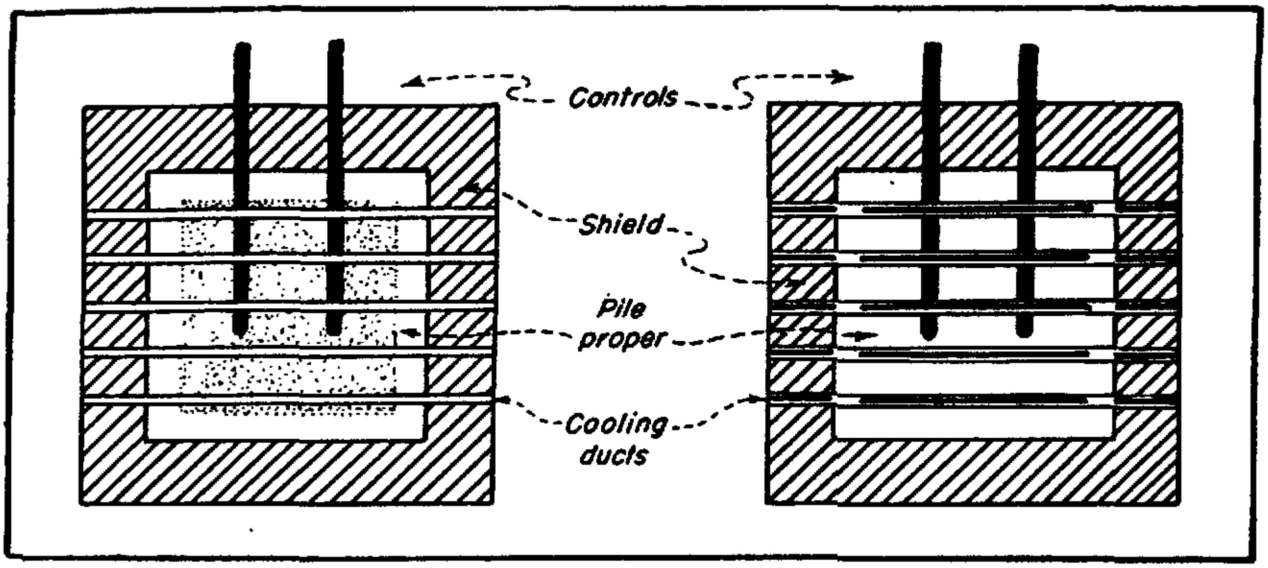
The first of these, U^{235}, is an isotope occurring in natural uranium in the proportion of one part in 140. Chemically, it is impossible to separate this from natural uranium, so it must be separated by mechanical or physical processes. These means of separation are extremely expensive. U^{235} has been separated by gaseous diffusion through porous barriers, by



Active core—contains a nuclear fuel, possibly a diluent, and, in some cases, a moderator



The pile proper, with the reflector and radiation shield



Sketch of pile showing control rods and means of energy removal. The ends of the cooling ducts must be plugged, baffled or shielded to prevent the escape of radiation through these holes in the shield

Figure 13. Elements of a nuclear reactor.

LOCATION	INITIAL DATE	CLASS & TYPE	NEUTRON FLUX WITHIN PILE NEUTRONS/CM^2/SEC	MODERATOR	COOLANT	POWER LEVEL	REMARKS
Argonne National Lab., Chicago	Dec 2 1942	Heterogeneous Thermal		Graphite	None	Approx. 200 Watts	Original pile first set up at University of Chicago
Argonne National Lab., Chicago	May 1944	Heterogeneous Thermal	1×10^{12}	Heavy Water	Heavy Water	More than 300 kw	
Oak Ridge National Lab., Tennessee	Nov 1943	Heterogeneous Thermal	1×10^{12}	Graphite	Air	More than 2,000 kw	
Los Alamos	1944	Homogeneous Thermal	1×10^{11}	Water	Water	10 kw	Known also as the water boiler type
Los Alamos		Fast		None			
Brookhaven National Lab., Long Island	Fall of 1950	Thermal	5×10^{12}	Graphite		Designed for 30,000 kw	

In the heterogeneous pile the fissionable material is localized in lumps or rods arranged usually symmetrically throughout the moderator structure.

In the homogeneous pile the fissionable material is uniformly distributed throughout the active portion of the pile.

Each of the above classes of piles can be of three general types: fast, intermediate (resonance) or thermal depending upon the energy of the neutrons that propagate the chain reaction.

Table I. Nuclear Reactors in the United States liquid thermal diffusion, by centrifuging, and by electromagnetic separation. However, these processes either give almost complete separation in one stage or two stages with a very low yield, or else a very good yield but with very poor separation per stage.

Fortunately, however, it has been discovered that plutonium 239, a man-made element, is fissionable; and $_{94}Pu^{239}$ can be made from the more abundant uranium 238 by neutrons, capture reaction producing an isotope 239 which emits a beta particle. It decays to neptunium, $_{93}Np^{239}$. This radioisotope is also beta-active, turning into isotope plutonium, $_{94}Pu^{239}$, which is relatively stable. Since plutonium 239 is entirely different chemically from uranium, it can be separated from the uranium by chemical means. Plutonium 239 is one of the materials now used for bomb construction.

The Armed Forces, through their research and development components, are actively engaged in developing the application of atomic energy for the propulsion of its ships, planes, and submarines.

One of the great problems to be solved in using a nuclear reactor pile for the propulsion of aircraft will be to find suitable shielding material to keep the weight of the power plant within tolerable limits.

Resumé of basic scientific facts upon which a chain reactor pile depends for its operation—

Fission of certain atomic nuclei releases large amounts of energy, roughly 4×10^{10} B. t. u. per pound.

The fission reaction may be made a self-sustaining or chain reaction if certain very exacting conditions are satisfied.

The rate of reaction may be varied over a wide range from that of explosive rate of speed to the steady low rate for research purposes.

Nearly all the energy appears as heat with only a small part as energy associated with more or less delayed radioactivity.

Fission is accompanied by intense radiation of lethal character.

The isotope of uranium with an atomic weight of 235 is the only fissionable isotope that occurs in nature; U^{233} and Pu^{239} are fissionable isotopes that may be made in reactors under proper conditions, by transmutation from thorium or from natural U^{238}.

CHAPTER 3

ATOMIC WEAPONS EFFECTS

Section I. COMPARISON OF ATOMIC AND HE BOMBS

The major difference between an atomic explosion and an HE explosion is the governing principle underlying each type. In the conventional explosive, such as TNT, the reaction is chemical, in which there is a rearrangement of atoms resulting in the explosive changing form from a solid to a gas. There also is a release of energy in the form of heat. In an atomic explosion the atoms themselves are broken down, the constituent particles being rearranged to form atoms of new elements. This reaction also is accompanied by the release of energy, and on a much larger scale.

The effects of both types of weapons is similar in that heat and blast are produced; the atomic bomb, of course, produces a great deal more than the largest TNT blockbuster. The bombs dropped over Japan were estimated to have the explosive effect of 20,000 tons of TNT, a considerable amount. There is one effect of the atomic bomb not found in the conventional weapon, nuclear radiation. As this type of radiation is ionizing, and therefore can be harmful to living organism, it causes an additional hazard to personnel. The precise effect of ionizing radiation will be discussed later in this chapter, as well as in the chapter on medical effects.

Section II. DESCRIPTION OF NUCLEAR EXPLOSION

The explosion of an atomic bomb is a nearly instantaneous release of a tremendous amount of energy. This energy is initially in the form of nuclear radiation and the kinetic energy of the fission products. This kinetic energy is quickly transformed into heat and the blast energy of the shock wave. About 90 percent of the total energy of the bomb is released within the first second, the remainder is released during the delayed beta and gamma emission of the fission products. Thus, there are three main effects of the atomic explosion—heat, blast, and ionizing radiation. Each of these effects will be discussed separately, using as a basis the so-called "hominal atomic bomb" with the energy release equivalent of 20,000 tons of TNT.

As the bomb explodes, a ball of fire is formed which expands rapidly to a diameter of about 300 yards. The initial temperature at the center of this fireball is in the vicinity of a million degrees C. As it expands, the temperature drops, and at the maximum size the temperature on the surface is about 7,000°C. This extremely hot fireball is the source of the radiant heat which is a serious hazard to personnel caught in the open. One of the trademarks of the atomic bomb is the brilliant flash which accompanies the explosion. This flash, when seen from a point nearly two miles distant, is estimated to be a hundred times brighter than the sun. This bright light can cause damage to the visual purple of the eye, resulting in temporary blindness, lasting from a few minutes to several hours. There is no evidence that any permanent injury may be caused. It should not be ignored, however, for to be blinded, even for a few minutes after an atomic explosion could be serious; for the pilot of a jet fighter it probably would be fatal.

The effects produced by a bomb—any bomb—depend largely upon whether the bomb is exploded in the air, on the ground or below the ground. In the atomic bomb, of vastly greater power than a conventional bomb, the difference in the effects produced is more marked. Three types of burst generally are considered; the air burst, in which the bomb is exploded high enough to prevent the fireball from touching the ground; the surface burst, in which the bomb may be exploded either on the surface or so close that the fireball actually touches the surface; and the subsurface burst, where the bomb actually is detonated below the surface of the ground or water.

Air Burst

In the air burst, the blast and heat effect have the greatest opportunity to do their work; hence, as a weapon of destruction this is probably the most efficient way to detonate the bomb. The exact height at which to explode the bomb may depend on the terrain below and the type of construction of the target buildings. The bombs that were exploded over Japan detonated in the vicinity of 2,000 feet over the target. In the discussion of the various effects produced i

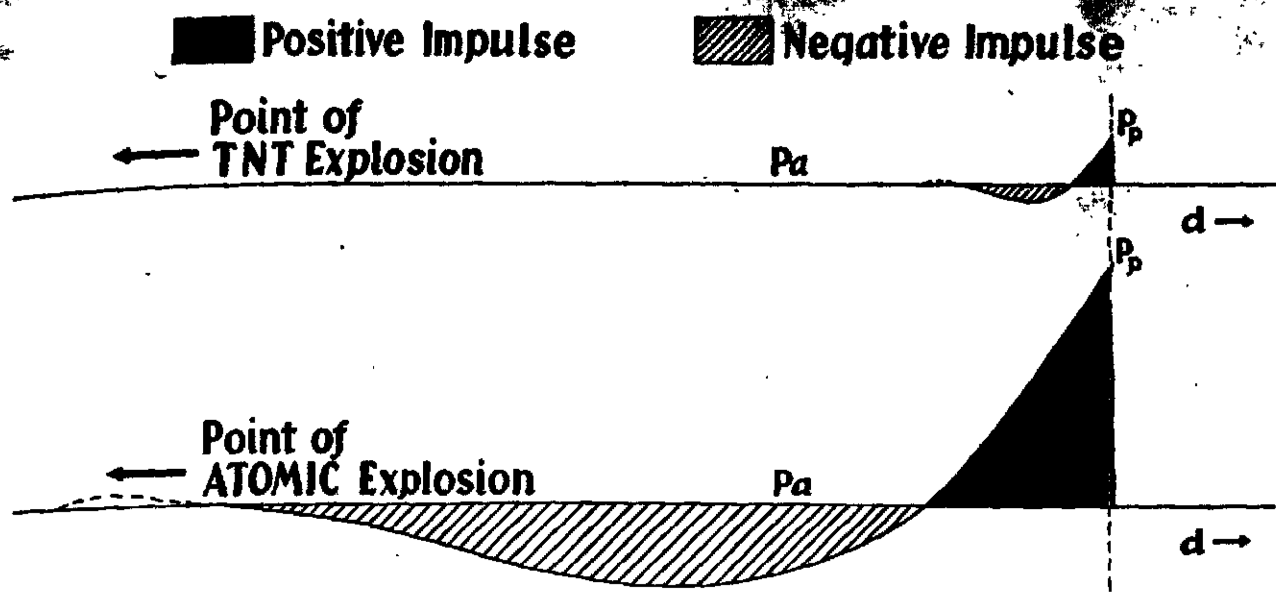


Figure 14. Shock wave pressures.

an air burst, it will be assumed that a 20 kiloton bomb (i.e., one which is equivalent to 20,000 tons of TNT) explodes at a height of 2,000 feet.

Blast Effect of an Air Burst

In any type of explosion, a phenomenon known as a shock wave is produced which emanates in all directions from the point of explosion. This shock wave consists of a wave of compressed air, the positive phase, in which the pressure is above atmospheric, followed by a wave in which the pressure is below atmospheric, the negative phase. As the positive phase moves out, the air is heated, causing the latter part of the positive phase to increase in speed, which in turn results in a "crowding" at the front of the wave producing a "shock front." Figure 14 is a graphical representation of the shock wave formed both by TNT and an atomic bomb. Note how the pressure rises from atmospheric to peak positive almost instantly and then subsides more gradually to atmospheric and below.

The negative phase in both cases lasts from three to three-and-a-half times as long as the positive phase. Note also that except for size both as to peak pressure and time involved, the atomic shock wave is identical to that of a TNT explosion. The positive pressure phase of a nominal atomic bomb, i.e., 20,000 tons of TNT equivalent, lasts about a third of a second at a point 1,000 feet from the explosion, and at 2¼ miles distant lasts a second and a quarter.

The blast effect of the air burst of an atomic bomb produces the greatest amount of material damage and, indirectly, may cause the largest number of personnel casualties.

The conventional bomb is generally set to explode on impact or sometimes slightly after impact, resulting in an explosion on or a little below the surface. This causes the force of the blast to be directed upward, and while destruction is complete in the immediate vicinity, the area affected by the blast wave is small. The atomic bomb, bursting high in the air, produces effects which are quite different from those of an HE bomb. The shock wave emanates from the bomb as an expanding sphere. When it reaches the ground directly under the bomb, a point known as "ground zero," the force is directed downward. At points farther from ground zero, the blast wave strikes at a greater angle from the vertical. A telephone pole directly under the bomb could be unaffected, while one located some distance away might be knocked over. When the shock wave strikes the earth, part of the energy is absorbed and the rest reflected. This causes an effect which is peculiar to an air burst and, hence, is peculiar to an atomic bomb, since the atomic bomb is the only one which normally might be exploded high enough to produce this effect. As the shock wave expands, the reflected shock wave expands along with it, like a gigantic soap bubble. At the point of intersection of the two waves, the primary wave is reinforced by the reflected wave, resulting in a wall of shock which may be from two to eight times the strength of the original shock wave. This reinforcing of the primary wave is known as the "Mach Effect" and is illustrated in figure 15. Thus we see that by exploding the bomb high in the air, the area of destruction and damage is greatly increased, not only by the fact that the blast is able to reach a large area but is actually reinforced by the Mach effect.

The actual magnitude of this shock wave is measured in terms of pounds per square inch of "overpressure," which is the increase over normal pressure. Figure 16 shows peak overpressure at various distances from ground zero and the structural damage which might be caused. The actual damage the shock wave will produce depends, of course, on many things. The type of construction is important. Reinforced concrete buildings will stand a much greater pressure than brick or frame buildings whose chief element of support is the walls. The effect of terrain is very important. The shock wave may be deflected by hills, skip over valleys, or in some cases, be reinforced by canyons. It is quite possible for houses to be damaged at a considerable distance from the point of explosion, while others nearer are untouched. In general, in the average city it may be expected that within a quarter of a mile of ground zero the destruction will be complete regardless of the type of construction. Out to a mile, reinforced concrete buildings will be badly damaged, while other types of buildings will be destroyed. Dwelling houses will probably be destroyed out to a mile and a half from ground zero. Minor damage can be expected out to a considerable distance. In Japan some windows were broken as far as twelve miles from the blast. Here the terrain was probably a factor, as some houses much closer were undamaged. As an interesting comparison, a hurricane wind of 100 miles per hour will exert a pressure of 30 pounds per square foot on a building. At a quarter of a mile from ground zero, the shock wave exerts a pressure of about 30 pounds per square *inch.* (30 psi), 144 times as great. According to present estimates, an overpressure of 30 psi will destroy any building found in the United States. The average home will be destroyed by an overpressure between 3 and 6 psi.

It has been stated previously that the blast effect of the bomb is indirectly the cause of most of the personnel casualties. The word "indirectly" is very important. The human being, in some respects, is a rugged animal and is extremely blast resistant. He can withstand a shock wave, with no ill effects, that would destroy a ten-story office building. It is estimated that to cause death or serious injury to a person, a shock wave in air must exert an overpressure of from 150 to 175 psi. At ground zero the shock wave reaches only about one-third of this value. There were no casualties in Japan that could be attributed directly to shock other than ruptured eardrums. Blast collects its toll of humans by its secondary effects. Collapsing buildings and flying glass and other articles are the real blast hazards, not the blast itself. Another secondary effect of blast is the fires started in the damaged buildings by overturned stoves, broken gas mains, etc. These fires result in a large number of burn casualties which add to those produced directly by the bomb.

Thermal Effects of an Air Burst

About 30 percent of the energy released by the bomb consists of electromagnetic radiation of ultraviolet, visible light, and infrared rays. The surrounding air absorbs much of this radiation resulting in the formation of the fireball. At the instant of detonation the temperature of this fireball is over a million degrees centigrade but as it expands the temperature falls off rapidly. One ten-thousandth of a second after the explosion, the fireball has reached a diameter of about 90 feet and the temperature is about 300,000°C. The fireball requires about 1 second to reach its maximum diameter of about 900 feet. At this time the temperature of the surface is in the neighborhood of 7,000°C. It also commences rising very rapidly and in a few seconds has reached an upward velocity of 300 ft/sec. During this time the fireball has been radiating heat intensely in quite the same manner as an open fireplace or an electric radiant heater. The heat waves travel through the air with the speed of light and apparently without producing any heating of the air. Although the heat radiated from the bomb is intense (the temperature on the ground beneath the bursts in Japan was between 3,000 and 4,000°C.), it acts for a very short period of time—about 3 seconds.

Of the various types of thermal radiation, the most serious are the infrared and visible radiation. While ultraviolet can produce serious burns (as is well known to anyone who has ever been sunburned), its high attenuation in air, plus the fact that it is of extremely short duration, reduce it to a minor hazard.

The effect of this radiant heat emanating from an atomic bomb burst produces a type of burn known as a "flash burn." Unlike an ordinary flame burn, a flash burn may be produced without actual contact with the source. As the radiant heat acts for such

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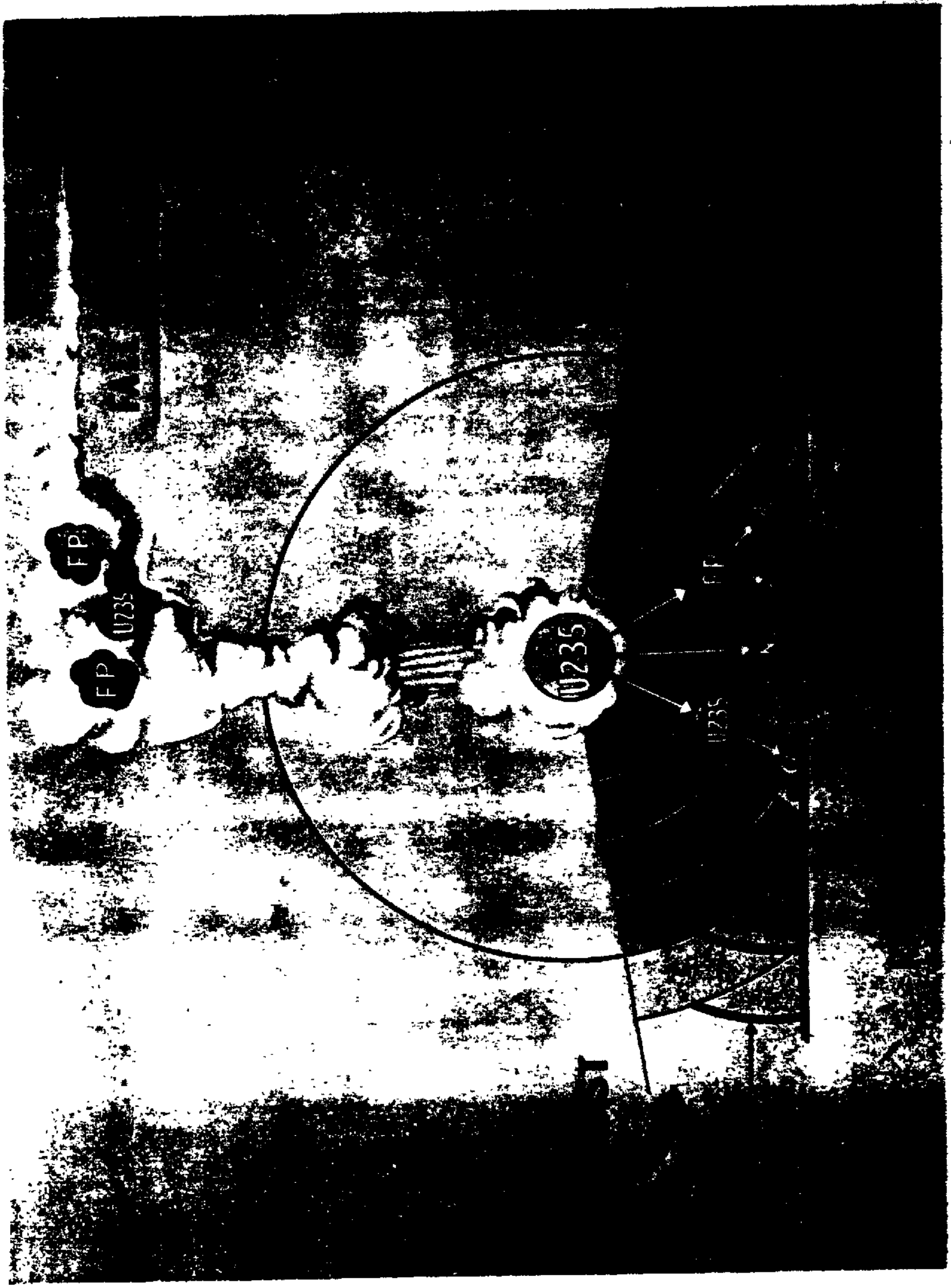


Figure 15. Hazards due to air burst of atomic bomb.

Wind velocity (mph)	Duration (sec)	Overpressure (psi)	Miles	Feet	Damage
					Limit of light damage at 8 miles.
50	1.25	1.5		12,000	Light damage to window frames and doors, moderate plaster damage, complete window damage.
			2.25		
60	1.23	1.7		11,000	Flash charring of telegraph poles. Roof and wall covering on steel frame building damaged.
			2.0		Partial damage to structures in area.
70	1.20	2.0		10,000	Blast damage to majority of homes. Severe fire damage expected. Flash ignition of dry combustible materials.
			1.75		
80	1.15	2.4		9000	Heavy plaster damage.
					Moderate damage to area.
100	1.12	2.9		8000	Severe damage to homes, heavy damage to window frames and doors, foliage scorched by radiant heat.
			1.50		
125	1.06	3.6		7000	
					Structural damage to multistory brick buildings. Roof tiles bubbled (melted by heat).
			1.25		
160	0.98	5.2		6000	Severe damage to entire area. Severe structural damage to steel frame building. 9-inch brick walls moderately cracked.
					Electrical installations and trolley cars destroyed. Multistory brick building completely destroyed.
			1.0		
200	0.90	7.4		5000	12-inch brick walls severely cracked.
					Steel frame building destroyed (mass distortion of frame). Light concrete buildings collapsed.
270	0.77	10		4000	Reinforced concrete smoke stack with 8-inch walls overturned.
			0.75		
					18-inch brick walls completely destroyed.
380	0.62	16		3000	
			0.50		Virtually complete destruction of all buildings, other than reinforced concrete aseismic design.
550	0.45	24		2000	Limit of severe structural damage to earthquake-resistant reinforced concrete buildings. Reinforced concrete building collapsed, 10-inch walls, 6-inch floor.
					Mass distortion of heavy steel frame buildings. Loss of roofs and panels.
			0.25		
800	0.37	36		1000	Decks of steel plate girder bridge shift laterally
				0	Air Burst of an Atomic Bomb.

Figure 16. Resumé of air burst effects.

a *short* time, shielding of almost any kind may be highly effective. The effectiveness of various materials used as shields depends upon the distance from the explosion. In Japan ordinary clothing proved an effective shield for persons who were beyond 1,500 yards from ground zero. Many of these people suffered severe burns on the exposed portions of their bodies, while their clothing offered complete protection. At a lesser distance from ground zero, however, clothing is of little or no protection. In this case the clothing would be set aflame, causing flame burns, and would probably disintegrate, allowing the radiation to reach the skin. Heat rays travel in a straight line, so only those persons directly in line with the flash will be affected. A person around the corner of a building or behind a large tree would not be burned, although the building or tree might fall on him.

One factor that has an important influence in shielding is the absorption qualities of the materials. Light colored materials reflect a large portion of the heat and will resist radiation that would char the same material in a dark color. This was apparent in Japan where many women had the designs of their kimonas transplanted to their backs in the form of burns; the light portions reflected the heat, while the dark figures absorbed and transmitted it.

Although the thermal effect of the atomic bomb will char combustible material as far as two miles from the point of explosion, and actually ignite wood within a mile, it is not directly the cause of many of the fires that spring up immediately after the explosion. Many materials that will char when subjected to the heat will not ignite due to the short time involved. Also, as the heat radiation precedes the shock wave, many fires which might be caused by direct thermal radiation may be blown out by the shock wave following.

Thermal radiation is strongly affected by the dust and moisture present in the atmosphere. For this reason, it is not possible to state definite thermal effects at various distances which would hold true under all conditions. On a clear day, a person in the open 6,000 feet from the explosion would receive third degree burns on the exposed portions of the body. If a dense haze were present he could stand in the open at the same distance and not be burned at all.

Thermal radiation of the bomb is more of a personnel hazard than a structural one, and as about 20 to 30 percent of the fatalities and 70 percent of the casualties in Japan were attributed to direct thermal radiation, it may be considered a very serious one. Thermal effects at various distances on various materials are shown in table II.

Section III. NUCLEAR RADIATION

The one effect of the atomic bomb which is peculiar to that weapon and not shared with conventional explosives is the nuclear or ionizing radiation that accompanies the explosion. These radiations consist of neutrons, alpha and beta particles, and gamma rays. Ionizing radiation is harmful to living organisms and, therefore, constitutes a personnel hazard in the vicinity of an atomic explosion. The results produced by this radiation on the human body are discussed in chapter IV.

The radioactive component of the bomb generally is considered in two categories—the radiation produced by the bomb during the first minute or so after detonation, and the residual radiation of land, water, and objects which may have become contaminated with radioactive products of the explosion. Some residual radioactivity may be induced in the ground or in salt water by the neutrons released during the fission process. The initial radiation itself may be divided into two parts—that radiation produced during the fission process, lasting only a few millionths of a second, and the radiation produced by the fission products. The radiation produced during the fission process, known as "prompt radiation," consists of neutrons produced during the chain reaction and gamma rays. As few of the gamma rays ever reach the air, the neutrons are the only significant radiation during this phase. When the chain reaction has ceased, the material which was fissioned consists of many radioactive fission products emitting beta particles, gamma rays, and a few neutrons. The neutrons emitted during this phase are so few in number that they may be considered of no importance, and as the range of the beta particles is so short (only a few feet in the air) the only radiation which must be considered is the gamma.

Except for the instantaneous flux of neutrons, the effective radiation in an atomic burst consists of gamma rays emitted by the radioactive fission products. These fission products are made up of about 60 different isotopes representing about 34 different elements. Probably all are radioactive to various

MATERIAL	EFFECT	CRITICAL ENERGY	EFFECTIVE DISTANCE
		cal./cm.^{2}	feet
Skin	Moderate burns	3	8,400
	Slight burns	2	9,600
White paper	Chars	8	6,000
	Burns	10	5,400
Black paper	Burns	3	8,400
Douglas fir	Chars	8	6,000
	Burns	11	5,200
Douglas fir (stain dark)	Burns	3	8,400
Philippine mahogany	Chars	7	6,300
	Burns	9	6,150
Maple (black)	Chars	8	6,000
	Burns	25	3,800
Cotton shirting (gray)	Scorches	8	6,000
	Burns	10	5,400
Cotton twill	Scorches	10	5,400
	Burns	17	4,400
Gabardine (green)	Brittle	7	6,300
	Burns	10	5,400
Nylon (olive drab)	Melts	3	8,400
Rayon lining	Scorches	3	8,400
	Burns	8	6,000
Wool serge (dark blue)	Nap gone	2	9,600
	Loose fibers burn	7	6,300
Worsted (tropical khaki)	Nap melts	4	7,600
	Burns	15	4,700
Rubber (synthetic)	Burns	8	6,000
Lucite	Softens	72	2,400
Bakelite	Chars	75	2,400

NOTE: *The effects listed above would result only on a clear day. The presence of dust or moisture in the air would reduce the effective distances considerably.*

Table II. Effects of thermal radiation degrees. Some have extremely short lives and are intensely radioactive, while others with longer half lives are not so intense. Each follows its normal process of decay, emitting beta and gamma in continuously decreasing amounts.

Figure 17 is a typical curve of intensity plotted against time. In this case, it is assumed that 1 hour after detonation the intensity of the fission products at a given location is one roentgen per hour. It can be seen that the intensity falls off rapidly immediately after the explosion but, as time goes on, the decrease in intensity becomes very gradual. This is the result of the highly intense short-lived fission products decaying into long-lived isotopes of comparatively low intensities. As some of these isotopes may have extremely long half-lives, the radiation, even though minor, may continue to exist for thousands of years.

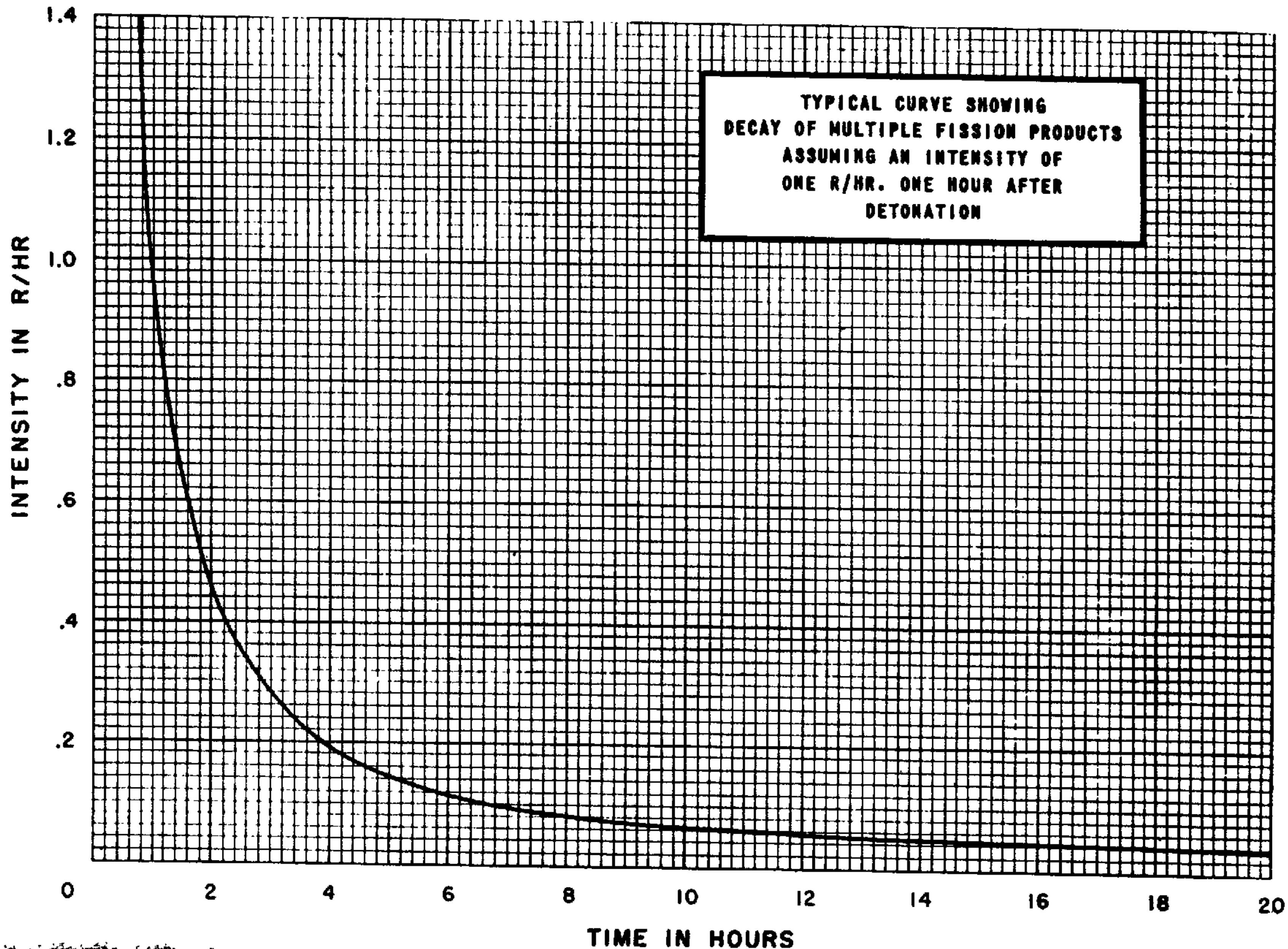
Although figure 17 is based on an initial intensity of one roentgen per hour, at 1 hour after detonation it will hold true for other initial intensities. For example, if 1 hour after the burst the intensity was found to be 100 roentgens per hour, then, from the curve we see that 4 hours after detonation the intensity is 19 roentgens per hour. For a ready rule of thumb, the intensity may be regarded as decreasing inversely as to time; for example, the intensity at a certain spot 10 hours after detonation will be approximately one-tenth that at 1 hour. This is a sufficiently accurate estimate for use in the field.

In the discussion of the thermal effects it was stated that almost immediately after the fireball formed it commenced rising at a rapid rate, initially at more than 200 m. p. h., so that it reaches an altitude of 15,000 feet in about a minute and a half. All the fission products are retained within this fireball and rise with it. Thus, even though the fission products radiate gamma for a considerable period of time, the rising fireball removes this source of radiation from the earth in about one minute. The atomic cloud moving rapidly toward the stratosphere is still a source of intense radiation, and a danger to airmen, but for the survivors below it may be forgotten. This cloud continues rising until it reaches the stratosphere, between 30,000 and 60,000 feet. At this point it spreads out, and the radiation particles are gradually diffused, thus causing a reduction in intensity, which is in addition to the natural radioactive decay.

General Effects of Radiation

It was stated in the discussion of thermal effects that shielding of almost any type could be very effective in preventing burns. This is not true at all concerning gamma radiation. Clothing and light materials, such as wood or fabrics, offer almost no shielding effect. Only heavy materials such as lead, steel or concrete can give any protection from this type of radiation. When speaking of shielding, the term "half thickness" frequently is used. It may be defined as the thickness of a certain material which is required to reduce the intensity of radiation by one-half. The half thickness of steel is 1 inch; thus, if a steel plate 1 inch thick were placed in a radiation field of an intensity of 400 r/hr, it would reduce the intensity to 200 r/hr; 800 r/hr would be reduced to 400 r/hr. This half thickness of materials depends mostly on their densities, ¼ inch for lead, 1 inch for steel, 3 inches for concrete and 5 inches for earth. The best defence against ionizing radiation is distance. Any radiation from a point source will diminish in intensity according to the law of inverse squares. In other words, if a point "A" is twice the distance from the source as point "B," the intensity at "A" will be one-fourth the intensity at "B," if "A" is three times as far as "B," it will be one-ninth, etc. Gamma radiation is similar except that there is an additional attenuation caused by the gamma photons reacting with particles in the air and giving up some of their energy. This causes a reduction of intensity by a factor of ten for each 800 yards distance from the point of explosion.

Without going to deeply into the medical aspects of radiation, it might be well to discuss the amount of radiation that will produce harmful or lethal effects on personnel. A total dosage of 450 roentgens received over the whole body in a short time, such as a few minutes, probably will be lethal to 50 percent of the people exposed. This is known as the MLD or "median lethal dose" of whole body radiation. A dose somewhat less than this might prove fatal to a few people, but most would recover. Conversely, a few people might survive a dose of 600 roentgens, but the majority would die. A person in the open would receive the MLD of 450 r at a distance of 1,300 yards from ground zero. The attenuation is so strong, however, that at 1,500 yards from ground zero only 150 r would be received, which would not be fatal and would result in sickness in only about half the people exposed. Shielding can be very important at these distances. For example, at 1,300 yards 3 inches of concrete would reduce the total dosage from 400 to 200 r, that is, from a dose that might be fatal to one that definitely would not be and might not even cause sickness. It has been estimated that 50 percent of the total dose is received during the first second after


TYPICAL CURVE SHOWING
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ASSUMING AN INTENSITY OF
ONE R/HR. ONE HOUR AFTER
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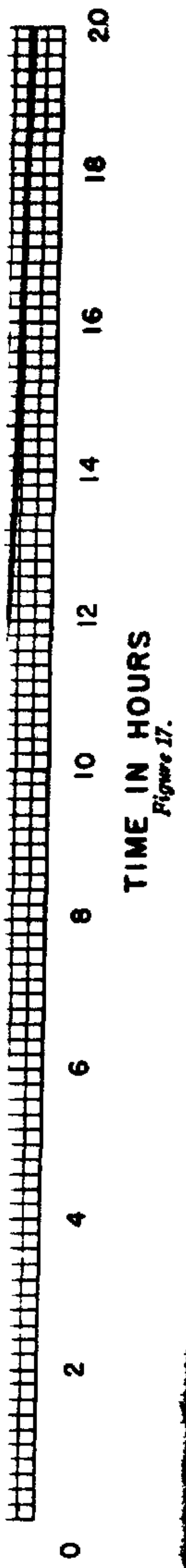
TIME IN HOURS

Figure 17.



the burst. If a person caught in the open could reach some cover, as behind a wall or in a slit trench, within a second after seeing the flash, a significant portion of the radiation might be avoided. This might mean the difference between life and death at such distances from ground zero that the unshielded dose is near the median lethal range.

Neutron Radiation

At the beginning of the discussion of radiation a neutron flux was described as emanating from the bomb during the first instant of explosion. Neutrons are similar to gamma rays in that they are ionizing and are harmful to living organisms. They also are highly penetrating. The neutrons, however, do not have the range of the gamma rays and for a 2,000 foot air burst would not be lethal for personnel in the open at distances greater than one-half mile from ground zero. At this distance the unshielded dose from gamma radiation would be over 2,000 roentgens, so that neutron radiation cannot be considered an added or individual hazard.

Residual Radiation

Residual radiation, as the name implies, is the emission of alpha, beta, and gamma rays by radioactive material which may remain in the vicinity of an atomic explosion. Although this type of radiation may be produced by neutrons striking the earth and inducing radioactivity in the elements therein, most of it results from the scattering of fission products. One other source of radioactivity is the uranium or plutonium which has not undergone fission but has merely been blown into minute fragments. These materials emit only alpha particles. They might become an internal hazard to personnel if deposited in a populous area in quantity. The internal hazard of radioactive particles will be covered in the chapter on medical effects. As was shown in the paragraph on neutron radiation, the neutron range is comparatively short, so in a high air burst only the ground in the immediate vicinity of ground zero would be affected, and only to a slight degree. The rising fireball which is followed by an upward rush of heated air forms a chimney-like effect that carries all the products of explosion to a great height before they have a chance to settle to the earth. These radioactive particles that result from the explosion of an atomic bomb are extremely small, ranging from diameters of about 1,000 microns (1 micron $= 10^{-4}$ cm or about one four-thousandth of an inch) to diameters of less than 5 microns. These particles are of such small size that they do not fall to the earth immediately, many of them remaining in the air for long periods of time. During the time these particles remain in the air they are losing their intensity, due to radioactive decay, and are being gradually dispersed by the wind, so this "fallout" of radioactive material cannot be considered a serious personnel hazard resulting from an air burst. If the force and direction of the wind is known for various altitudes up to 60,000 feet, a plot may be made showing areas likely to be affected, if at all.

Thus, we see for a high air burst the residual radiation produced is extremely minor, and when compared with the blast and heat effect of the bomb, it becomes negligible. While ionizing radiation is produced and represents a definite personnel hazard, this ceases to be of any dangerous intensity at ground level after about a minute. Rescue work, therefore, can be commenced almost immediately after an air burst and should not be delayed on the supposition that dangerous radioactivity may exist.

Surface Burst

An atomic bomb exploding on or near enough to the surface so that the fireball touches the earth is known as surface burst, and the general effects are different from that of the high air burst. The blast effect of a surface burst is much more intense in the immediate vicinity of the bomb but the effective area of damage is considerably less. This is caused by the shock wave being projected outward and upward rather than downward, and the fact that the burst is so close to the ground the Mach effect does not take place. Thus, we see as far as blast damage is concerned, the bomb is more efficient when exploded high in the air than when exploded very close to the surface. The result desired from any bomb usually is widespread damage rather than complete annihilation of a small area. With respect to thermal radiation effects, the tremendous heat of the fireball would melt or vaporize most objects in the immediate vicinity but the shielding effect of buildings might reduce the effective area. The effect of the immediate gamma radiation of the surface burst would be quite similar to the air burst, but some shielding would be provided by structures. The residual radiation produced by a surface burst will be quite appreciable. As the bomb is much closer to the ground, the neutron flux is much more intense and will cause considerable induced radioactivity. In addition, many fission products will be fuzed into the ground by the heat of the explosion or be deposited by condensation. The fallout may be a cause of residual radiation, as there will be considerable dust and small fragments of matter drawn up into the cloud by the explosion. These particles, with fission products adhered to them, and being of larger size than most of the fission fragments, will fall to earth while the activity is still intense. Shortly after the Alamogordo test, some cows about 15 to 20 miles from the explosion were subjected to the fallout of dust containing radioactive particles. However, other than loss of hair, which later grew back a different color, the cattle showed no permanent ill effects.

Subsurface Bursts

As the only subsurface burst of an atomic bomb to date was the wellknown "Baker Test" at Operation Crossroads, which was an underwater burst, that type of burst will be described. In this type, which is radically different from the air burst, the thermal effect and immediate radiation are practically negligible, while the residual radiation is very extensive. The underwater shock wave produced by the explosion will sink the strongest ship within a radius of 600 yards and cause damage to hull and machinery up to a range of 1,500 yards. The underwater burst at Bikini sank nine ships. However, it must be taken into consideration that the ships were moored very close to each other for the purposes of the experiment.

The most striking effect of an underwater burst is the residual radiation or contamination produced. Nearby land and water and the objects thereon, such as houses and ships, become contaminated when radioactive particles are deposited on them and adhere to them. Contaminated objects appear to be radioactive but actually they are not. When the radioactive particles are removed, the objects themselves no longer give any indication of radioactivity. This contamination and the methods used for decontamination will be discussed more fully later. When the bomb bursts underwater, as at Bikini, the fission products are trapped by the water and carried upward in the huge column of heavy spray. This column drops back into the water almost immediately, carrying the fission products back with them. The immediate gamma radiation at this point is negligible, as only the fission products on the outside of the column are effective, and the column is approximately 2,000 feet in diameter and reaches a height of about 5,000 feet. The thermal effect of the bomb in this case also is negligible, as nearly all the heat is absorbed by the water. At Bikini, when this column of heavy spray fell back into the water, it produced a peculiar effect known as the "base surge." This consisted of billowing clouds of radioactive mist expelled outward from the falling spray column. At first it moved out with a speed greater than 60 miles per hour but slowed rapidly to a speed of only a few miles per hour. It gained in height as it moved, reaching a height of over 2,000 feet at the extent of its outward movement. As the base surge moved outward, a rain commenced which lasted for about an hour after detonation. At this time the mist clouds rose from the water to a height of about 1,500 feet. It eventually formed cumulous clouds which joined and became indistinguishable from the cumulous clouds which were present at that time. The base surge, as it moves outward from the base of the spray column, is highly radioactive, contaminating everything in its path. Its radioactivity diminishes rapidly, however, due to the rainout depositing fission products and the natural decay of the fission products contained within.

In addition to the fission products, a certain amount of contamination results from the neutron-induced radioactivity of the sodium present in sea water. Sodium is one of the elements that is particularly susceptible to neutron activity. However, this activity is only a small part of the total activity due to fission products.

The contamination of the target ships at Bikini caused by the underwater burst was quite extensive. It was many days before some of the ships could be boarded for more than short periods of time. Although the contamination crews went to work immediately, it became apparent that complete decontamination would not be practical in view of the expense involved and the fact that the ships were obsolete and many badly damaged. It was for this reason many ships were sunk in deep water, although, unfortunately when reported in the press the impression was given that the radioactivity present could never be removed. There was no ship at Bikini that could not have been completely decontaminated and made entirely liveable had the situation warranted. In fact, some of the contaminated ships were made completely habitable and returned to service.

The base surge, which produced such a large amount of contamination at Bikini, is a phenomenon which belonged to that particular explosion, i. e., the depth of the water and the depth of the bomb when

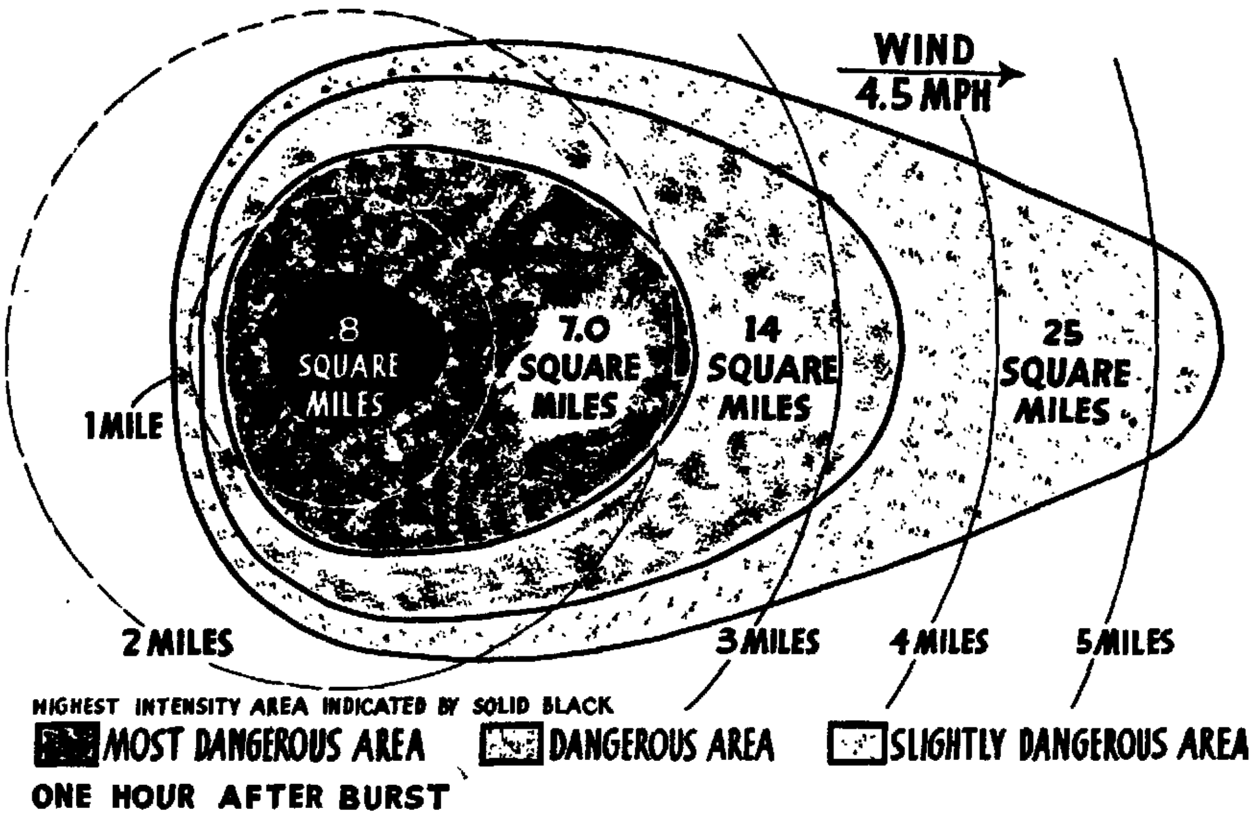


Figure 18. Contamination caused by sub-surface atomic burst.

it exploded. The effect that would be produced under different conditions is a matter of conjecture. See figure 18.

All the information that is presently at hand concerning subsurface bursts is gathered from the underwater test at Bikini. As there has been no actual underground test, the effects of this type of explosion can only be estimated. In this case the shock wave would travel underground rather than through the air, causing an earthquake effect which would undoubtedly be highly destructive to buildings in the immediate area. The air blast and the thermal radiation would be absorbed by the earth. Immediate gamma radiation would be negligible; however, the residual radiation and contamination produced would be extensive.

Contamination and Decontamination

Residual radiation or contamination produced by an atomic bomb may be of two types—radioactivity induced in certain elements by the neutron flux, and that produced by the scattering of fission products and unfissioned nuclear material. Induced radioactivity is very slight in the air burst, and even in a surface or subsurface burst would be by far the minor source of contamination. It is true that after the Able Test at Bikini some induced radioactivity was detected on the target ships. Salt on mess tables and silverware were affected, as sodium and silver have high capture cross-sections for neutrons. The Able burst, however, although classed as an air burst, was actually very low, only a few hundred feet above the water. If it had occurred 2,000 feet in the air, which is considered the optimum altitude for an air burst for a bomb of this size, it is doubtful if any radioactivity would have been induced.

The main cause of contamination is the adherence of the radioactive particles to the ground or objects. In this case the object which has been contaminated by radioactive particles will appear to be radioactive due to the presence of these particles. If these particles are removed, the object will lose all signs of radioactivity. In other words, radioactivity is not contagious; radioactive particles will not transmit their radioactivity to the object they happen to adhere to. However, this radioactive contamination is easily spread by direct contact. In this case the particles themselves are transferred. Care must be taken when handling objects known to be contaminated to prevent this spreading.

These radioactive particles actually are made up of many unstable atoms. As the atoms themselves are the cause of the radioactivity, they are completely unaffected by any chemical process such as burning, melting, or combination with other elements. In effect, this means that there is no way of neutralizing radioactive contamination by the addition of some other chemical, as can be done in the case of mustard gas by the addition of chloride of lime. An object may be decontaminated only by physically removing the radioactive particles and depositing them in a place where they may continue their radioactivity harmlessly. This is one of the biggest problems where decontamination is concerned—to remove the particles without spreading them over a wide area and thereby creating an even larger problem.

The most elementary method of decontaminating personnel and small objects is simply scrubbing with soap and water. A good detergent added to the water helps, as it breaks down the surface tension making the water "wetter" and enabling it to get into tiny pores and cracks and flush out the minute particles. Citric acid has been found to work well for this purpose, as well as many commercial detergents. It should be brought out that any chemical added to the water serves merely to assist the water in its task of removal of radioactive particles. It does not in any way reduce the radiological effect. Clothing may be decontaminated by vacuum cleaning or laundering. However, the vacuum cleaner must have a filter attached to trap the particles, and the laundry must be especially equipped so the waste water will not spread the contamination. Porous materials are considerably harder to decontaminate than hard or smooth surfaced materials. In this case the small particles become deeply imbedded, and it may be necessary to remove part of the surface. Here, again, the problem of avoiding the spreading of contamination comes up. Wet sandblasting is quite effective and prevents the dispersal of contaminant in the air. A land area which is contaminated may be cleared for the passage of troops by employing bulldozers to scrape a passageway. A cut of 6 inches ordinarily will remove all radioactive particles.

Personnel Precautions

Personnel working in a contaminated area should wear protective clothing consisting of coveralls, gloves, boots, and a respirator. The latter is to prevent the breathing of radioactive dust which might have serious consequences. The protective clothing would be of no protection against gamma radiation, but any known contaminated area would have to be monitored for gamma prior to anyone entering for decontamination work. The reason for the protective clothing is to prevent beta and alpha emitters from coming into contact with the skin. Intense beta radiation may cause burns and lesions of the skin which are slow healing. Also, it is much easier to unzip a coverall than to scrub for hours in a shower, although the shower also should be included as a further precaution.

SUMMARY OF ATOMIC BOMB EFFECTS

Air Burst

In this type of burst the blast and heat effect of the bomb will cause destruction and damage over a wide area. The immediate gamma radiation will be a definite personnel hazard for a minute or two after the explosion but will cause only a small percent of the total casualties. Residual radiation and contamination will be negligible.

Surface Burst

The blast and heat effect will be somewhat localized, i.e., will be more intense in the immediate vicinity of the burst but will not cover as much of an area as that produced in the air burst. The immediate radiation will be present and the effect will be similar to that of the air burst. Residual radiation probably will also be present in varying degrees. It might present a serious problem in connection with rescue work, fire fighting, etc. Radio-activity might well be spread over a considerable area by fall-out.

Subsurface Burst

The effect of this burst is somewhat similar to the surface burst. A portion of the blast effect will be absorbed underground producing a shock wave. The blast effect in air will be less than either the air or surface burst but will be of considerable force. The thermal radiation probably will be negligible. Immediate gamma radiation will be considerably reduced but residual radiation probably will be extensive. The spreading of contamination will be considerably increased if a base surge is formed.

CHAPTER 4

MEDICO-BIOLOGICAL EFFECTS OF ATOMIC WEAPONS

Section I. GENERAL

A single atomic bomb of the type dropped on Nagasaki and Hiroshima during the war can lay waste the heart of a large city and injure and kill great numbers of people. In the two Japanese cities, over 100,000 were killed, and nearly as many were injured. If a bomb were dropped in such a way as to leave the area contaminated with radioactive materials, other casualties might result and rescue and repair work would be hampered. The area of damage, the number and kind of casualties, and the extent of contamination would depend on how powerful the bomb was, and on how it was used—whether at high or low altitude on a clear or stormy day, or exploded in a river or harbor.

Each way in which a bomb was used would have its own particular type of hazard. In some cases, the area of damage would be at a maximum; in others the area of damage might be reduced but radioactive contamination would be more severe. In these discussions, we are primarily interpreting data derived from the Japanese bombings in which an atomic bomb, considered as roughly equivalent to setting off 20,000 tons of TNT, was exploded at a height of about 2,000 feet above the earth on a clear day. This was about the altitude at which a bomb of this power is estimated to have the greatest effect. Higher than this, its blast effects would be weakened; lower than this, the circle of damage would be reduced.

The Power of the Bomb

The Hiroshima and Nagasaki bombs caused total destruction and serious damage to buildings—and death and injury to people—for 2 miles from the point at which the bomb was set off; the extreme limit of damage was about 4 miles. More powerful bombs could cause a wider area of damage, but very great increases in explosive force are necessary in order to accomplish relatively small increases in the area of damage. For example, it would be necessary to double the power of a bomb in order to increase the radius of severe damage and injury by one-fourth from 2 to 2½ miles. Estimates based on the type of bomb dropped over Japan can be used as a rough basis for discussion and planning.

The Way Bomb Is Used

A high air burst, such as that in Japan, leaves no dangerous amounts of radioactivity on the ground. A bomb exploded in the air at low altitude, as in the Alamogordo test, will pulverize and vaporize materials in its immediate vicinity. It will not affect as wide an area, and the screening effect of hills will be increased since the explosion takes place closer to the earth. Radioactive contamination will, however, be severe within a limited area.

An underwater explosion of an atomic bomb also might cause serious contamination. The area affected would depend on where the bomb exploded, on the combined depth of the water and the softbottom, such as mud, and upon the direction and force of the wind. At Bikini, the underwater (Baker) test caused what is known as a base surge, a 200- to 300-foot "wave" of heavy radioactive mist which spread outward from the base of the mushroom tower of water, turned into a low-lying rain cloud and precipitated radioactive materials over the surrounding area. If the explosion of a bomb caused such a base surge, contamination of any adjacent land areas would result. Other types of injuries from the explosion itself, however, would be reduced.

Effects upon People

The effects of the burst of an atomic bomb upon people are essentially the same as those caused by an amount of TNT that releases an equivalent total of energy, but with certain added factors. Mechanical injuries suffered in the collapse of buildings will predominate in both cases. The main differences are first, the greater amount of radiant heat released by an atomic explosion; second, the large amounts of light, including ultra-violet; and third, the large amounts of nuclear radiation.

Injuries to people from an atomic bomb can be divided into four general categories—those caused by the blast pressure wave directly; those caused when buildings are wrecked; those caused by burns, either in the wreckage or from radiant heat; those caused by nuclear radiation, either directly or through residual contamination.

In the case of an underwater blast, the water absorbs the radiant heat, light, and nuclear radiation, hence direct injuries from these sources do not occur. The contamination absorbed by the water, however, is spread whenever a base surge is formed.

In the case of such a high air blast as in Japan, some 15 to 20 percent of the deaths probably will be caused solely by nuclear radiation. The remaining 80 to 85 percent will be caused primarily by injuries suffered in the collapse of buildings and by burns, although many of these also suffered severe radiation exposure.

Practically all the direct injuries caused by the radiant heat take place within about 2 to 3 seconds after the initiation of the explosion. Japanese people in the open suffered third-degree burns up to 1,500 yards and second-degree burns up to 4,000 yards. Nuclear radiation continues for 90 seconds but most of it is concentrated in the first few seconds, 50 percent occurring in the first second. People suffered injuries from nuclear radiation, but beyond 1¼ miles injuries fell off sharply. The shock wave from the blast sweeps outward rapidly from ground zero and, in the case of Japan, took 8 seconds to travel 2 miles to the perimeter of damage. Injuries from its effects occurred throughout this region.

In the following sections are discussed: (*a*) the type of injuries caused by an atomic explosion, and the extent to which they occurred in Japan at various distances from ground zero; (*b*) the nature of the radiation hazard, the effects of exposure, and some of the treatments for acute radiation sickness; (*c*) the nature of the hazard from radiological contamination—not encountered in Japan—and some of the precautions that can be taken against it.

Section II. INJURIES FROM ATOMIC BOMBS

Air Blast Effects

Air blast effects on people fall into two categories: (a) Those caused directly by the pressure wave of the blast, and (b) those caused indirectly by collapse of buildings, flying wreckage, and by people being thrown against solid objects.

Direct Injury

Direct blast injury may occur wherever the air comes into contact with body surfaces, particularly, the intestinal tract, the stomach, the lungs, the ears, and the sinuses about the nose. Greatly increased pressure, especially if the increase is sudden, can tear these tissues. Practically no injuries of this sort were reported in Japan among survivors.

In the water, the dangerous level for pressure is about 500 pounds per square inch. In an underwater atomic explosion, any person immersed in the water probably would be killed or seriously injured up to 2,000 yards from the zero point.

Indirect Injury

Secondary blast injuries are an important cause of death in an atomic bomb explosion. Since practically all brick and light masonry buildings with weight-bearing walls in the blast area will be wrecked, wooden buildings flattened, and the doors and other partitions of blast-resistant steel-reinforced concrete buildings blown out, people in or near these buildings will be killed or injured by collapse of structures, and by missile effects of debris. Among such injuries will be crushing, fracturing of bones, and lacerations and bruises of various types. Mechanical injuries resulting from atomic bomb damage vary in no way from those that would be produced by other explosives or missiles except in the number of casualties.

Flying glass contributed a large share of superficial injuries, to be expected in any powerful explosion. In Japan, for example, cases were reported of glass fragments having penetrated over an inch beneath the skin. However, the clinical course of Japanese patients with mechanical injury showed that these injuries were not unique and such impairment as occurred was clearly attributable to the usual causes such as infection, loss of blood, and starvation.

Injuries Due to Heat and Light

Severe burns were caused both by the radiant heat from the explosion of the atomic bomb (flash burns) and from the fires that broke out in the wreckage (flame burns). Those who looked directly at the burst suffered only temporary dazzling and loss of vision. Temporary blindness resulted when the intense light bleached out the substance within the eyeball called "visual purple," and persisted from seconds to several hours until the body could manufacture a new supply.

Where hemorrhages of the eye occurred, it was probably from the general systemic effects of nuclear radiation. Conjunctivitis was common, but this infection of the outer eye was caused by smoke and dust

Flash Burns

The flash burns caused by an atomic explosion may be first degree, merely reddening the skin; second degree, causing blisters; or third degree, damaging all layers of the skin. The severity of an individual's injury, as with other types of burns, depends upon the degree of the burns, as well as upon the proportion of the body's total skin area that is affected.

Atomic bomb flash burns differ from those caused by other types of explosion, since they are due to radiant heat rather than to hot gases, as in the case of shell burst or gasoline explosions. They are readily distinguished because atomic flash burns are sharp in outline and are oriented to the point of the explosion. Shadow effects are prominent. An ear, for example, might be badly burned yet the skin behind the ear be unharmed.

Loose clothing afforded some protection against atomic flash burns, and color also had a protective effect. White clothing tended to reflect the radiant heat, while darker clothing absorbed it. Cases were found where the dark colored patterns on light colored clothing were burned on the skin of the patient. Tight clothing affords less protection than loose fitting clothing. Skin burns were more severe at places where the clothing was tight. For example, on the shoulders where the shoulder straps were tightest burns were more severe.

Flame Burns

The flame burns in Japan mostly occurred when people were trapped in the wreckage of buildings which afterward caught fire. A conflagration may be expected to follow any atomic bomb blast. Not only is the radiant heat sufficient to ignite wood and lighter materials close in, but the collapse of structures overturns stoves and furnaces, breaks electric wires, and ruptures gas lines above ground. About 70 percent of Hiroshima's fire-fighting equipment was destroyed, firemen were killed, the water supply was disrupted, and streets were clogged with debris.

The uprush of the atomic cloud after the explosion causes an inrush of wind, and heat from fires augments this effect. At Hiroshima a "fire storm" resulted, with gale-winds sucked inward toward the center by the continued uprush of hot air. This did not occur at Nagasaki, but must be assumed as a danger in an atomic blast. At the very least, fires about the perimeter will tend to consolidate and cut off help from people trapped within the blast area.

Burns suffered from flames, in such cases, differ in no way from those encountered in any ordinary intense fires. If the case is not complicated by injury from nuclear radiation, the determining factors in survival and rate of recovery will not vary from those of a comparable ordinary burn. Where radiation injury has been suffered, infection will be a grave danger.

Among the injured in Japan, there were many cases where excessive scar tissue (*keloids*) formed, and many of the survivors have contraction deformities resulting from improper care of burns and other injuries during the healing process. The deformities and the keloids are not specifically related to exposure to the atomic bomb, but rather to impaired healing and to infection. The keloids also apparently stem from a tendency in the Japanese as a race; and burns suffered in non-atomic bomb raids resulted in comparable amounts of scar tissue. Adequate medical care would reduce the amount of keloids and prevent much of the crippling.

Had proper medical care been available, it is also probable that many of the Japanese who died from burns, as from other causes, might have been saved. The death totals must be weighed in relation to the fact that all medical care was totally disorganized for days after the atomic blast.

Adequate care to injuries and burns suffered in an atomic explosion present a problem of great magnitude. While the types of injuries, aside from the radiation hazard, are similar to those encountered in ordinary bombing or other catastrophe, the large numbers or individuals involved in an atomic blast, and the general chaos that results, present a problem whose solution requires a great deal of careful planning and preparation.

Section III. THE RADIATION HAZARD

The nuclear radiation that causes direct injury in an atomic explosion includes neutrons and gamma rays. The former are tiny invisible particles driven out of fissioning atoms; the latter are invisible electromagnetic waves very similar to powerful X-rays and constitute the greatest radiological danger in an atomic blast. Both forms of radiation cause the same type of injury. They penetrate deeply into the body and ionize the atoms that make up the various elements—carbon, nitrogen, hydrogen, and oxygen among others—so that the atoms no longer are neutral electrically, but carry a positive or negative electrical charge which makes them violently reactive chemically. Nuclear radiation, or ionizing radiation, disrupts the complex combinations of these elements and thus changes the proteins, enzymes, and other substances that make up our cells and bodies. As a result, the cells are injured or killed, and bodily functions can be affected; if enough cells are damaged or killed, the person becomes seriously ill or dies.

This ionizing radiation ordinarily cannot be detected by the senses. If one touches a hot stove, the sensation of heat and resulting tissue damage is immediate. But one may receive an amount of ionizing radiation that will produce far more serious tissue damage than a burn without any sensation. Although chemical and physiological changes are produced almost instantly, no damage will be apparent for several days.

Beyond these general facts cited, very little is known about the exact mechanism by which radiation harms living molecules, cells, and tissue. The clinical effects have, however, been extensively studied in Japan, and in the United States a Nation-wide research effort to investigate these effects has been underway since the early days of wartime development.

Acute Radiation Illness

The clinical findings in Japan show that people exposed to heavy radiation suffer various injuries, sicknesses, and malfunctions which together are called the acute radiation syndrome. Physicians find that the severity of the symptoms is related importantly to two factors—the amount of radiation absorbed in a single dose, and the proportion of the body exposed.

It is possible to expose a skin cancer an inch in diameter to 5,000 roentgens of radiation (X-ray) without any effect on the patient other than that upon the cancer cells and, some scarring of adjacent normal tissues. But one-tenth this amount of radiation (about 500 roentgens), given over the whole body probably would prove fatal. Whole body irradiation of 450 roentgens is believed to be the dose that will kill about half of all the persons exposed to it (a dose called the human LD-50, or 50 percent lethal dose). Half of that amount of whole body irradiation, 225 roentgens, would cause radiation illness and, in rare cases, might result in death. The degree of acute radiation illness, and the probability of recovery or death, thus will vary sharply with the dosage received. The syndrome also can result from radioactive materials absorbed and lodged widely within the body where they then could emit their destructive radiation at close range. This danger from internal radiation is discussed later. Here, we are concerned with the effects of external radiation.

Results of Exposure

Clinical observations make it clear that heavy external exposure to penetrating radiation causes a massive break-down of the body's tissues, particularly in certain organs of the body. Since destruction of cells in various tissues reaches its height at different times after exposure, symptoms from these injuries will occur at different times. Two features make this type of body damage unique.

1. No two organs or tissues of the body suffer exactly the same amount of damage. Lymphoid tissue, bone marrow, the sex organs, and the lining of the small intestine suffer heavy damage. Muscles, nerves, and fully grown bone are not so easily injured. Other tissues, such as skin, liver, and lung, lie in between these extremes.

2. Unless the radiation has been extremely heavy, cells may not die for hours or days. For a week after skin is injured, it may show only a surface reddening and swelling of the underlying tissues. Blistering and loss of dead skin may be delayed for 2 weeks.

The course of illness in acute radiation syndrome can be described from the case records of Japanese exposed to atomic bombings, where their injuries were uncomplicated by blast damage or flash burns. Among Japanese who received 600 roentgens or more of radiation, the onset of the syndrome was violent and, in 75 percent of the cases, the first symptoms appeared within a half hour of exposure; great weakness followed and death sometimes occurred within 24 hours. Some patients lived 10 days. Among those receiving around the LD - 50, or 450 roentgens, the first symptoms might not appear for several hours and, after the first onset, the patient might be able to carry on normal duties for a week. One soldier in Japan, exposed in this way, afterward marched 15 miles with a full pack.

The sequence of symptoms among all exposed to heavy radiation was roughly the same, but the time intervals of various phases of the illness varied according to the severity of the exposure. Those who received around 450 roentgens or less developed additional symptoms—loss of hair and severe infections. The illness of a typical patient among the latter group goes through four phases:

Phase I. Within an hour or so after exposure, the patient becomes *nauseated, vomits,* and *suffers* general prostration and weakness. Diarrhea may occur and his blood pressure may fall a little. In general, the heavier the dosage, the more ill the patient will be. This phase is quite similar to the "radiation sickness" suffered by patients treated intensively with X-ray or radium.

Phase II. After the first onset of the illness, symptoms tend to disappear, and for a period of a few days to several weeks the patient feels less ill. For patients who have suffered the heaviest radiation, this period will be short. Reports have stated that Japanese injured by radiation alone were entirely without symptoms during this time, but the best information is that they were sick people who, because of the emergency, drove themselves to do what had to be done.

Phase III. The illness reaches its height during this phase. Whether or not the patient survives depends on his ability to endure this acute stage. The patient becomes apathetic and develops a fever and rapid heart action. He becomes increasingly weak and loses weight. He loses his appetite, may become nauseated and suffer severe diarrhea which is sometimes bloody. Small hemorrhages may appear in the skin and the gums bleed. In severe cases, infected ulcers may spread throughout the mouth and alimentary tract. The hair may fall from the head and body about 3 weeks after exposure.

The slightly injured recover quickly, but those who receive a heavier dose of radiation may continue gravely ill for weeks. The most severely injured may grow progressively worse over a period of weeks and finally succumb, or may die within a few days.

Phase IV. Patients who survive enter a convalescence during which a feeling of weakness and fatigue are the outstanding symptoms. It may be months before the patients recover normal strength and weight. The skin hemorrhages disappear and the hair, if lost, gradually regrows. Usually within 6 months, the patient feels completely well. All usual methods of examination indicate that, by this time, the patient is normal. Nevertheless, it is too soon to say that survivors will not suffer further ill effects.

Other Reactions

Besides the symptoms described, the acute radiation illness includes damage that can be detected only by laboratory tests—changes in blood cells, in male sex organs, and in the functioning of other organs.

Several symptoms of the third, or acute, phase of the illness stem directly from injuries to certain elements in the blood. Infections and ulcerations arise because radiation destroys white blood cells that normally aid in combating bacteria. A few days after radiation exposure, the number of white cells declines and, in severe cases, the cells disappear almost entirely. The skin and gum hemorrhages seemingly are connected with a fall in the number of platelets in the blood, since these substances play a role in the clotting of the blood. Other causes, such as an increase in anti-clotting substance that resembles heparin, a normal blood chemical, also contribute. Platelets begin to decline only after an interval of days and, where the patient survives, reappear during convalescence. A third, and very serious, effect upon the blood, the decline in the number of red cells, causes anemia and contributes to the general weakness and debility so marked in acute radiation illness. The decline in the number of red cells starts immediately after exposure and may continue for weeks.

Microscopic studies of tissue, amplified by more complete research with animals, indicate these blood changes are caused by radiation damage to the bone marrow and to the lymphoid tissue where these various cells are born. And the injury to tissue, as well as the course of illness in the patient, can be traced to damage to the cells. Radiation causes the cells to swell, disorganizes their structure and stops them from reproducing themselves. The stoppage of cell division occurs immediately after irradiation; structural changes appear more gradually. The most spectacular change is the collapse of certain parts of the cell, and the shrinkage of the nucleus followed by death and disintegration. The interruption of cell division is temporary, but when new cells again begin to divide they often show bizarre changes in their inner structure.

Treatment of Radiation Injuries

Many people believe that very little can be done in treatment of radiation casualties. This is true in case of a lethal dose; but certainly is not true when the exposure is in the median lethal range. Many borderline cases can be saved by—

a. Good medical and nursing care.

b. Whole blood transfusions, given as may be required in the individual case until the bone marrow has had time to regenerate and produce blood.

c. Control of infection by antibiotics, such as penicillin.

d. Intravenous feeding to supply necessary sugars, proteins, and vitamins.

e. Control of the bleeding tendency by use of drugs.

Whole blood would be required in great quantities, primarily, to treat the casualties suffering from mechanical injuries and burns; secondarily, to treat victims of ionizing radiation.

It has been estimated that for a catastrophe such as at Hiroshima approximately 250,000 pints of blood would be needed, 80,000 per week for the first 3 weeks. Subsequent to this, there would be only a nominal requirement for whole blood. This time relationship favors the possibility of obtaining blood from donors, processing it, and transporting it to the operations area, as it envisaged in the blood program of the American Red Cross.

Equally, the time factor would permit evacuation of victims to unbombed areas where better nursing care, so essential to recovery, could be better provided.

After Effects of Radiation Exposure

Many people who recovered from radiation sickness itself afterward died from tuberculosis, pneumonia, or some other disease which appeared as a complicating factor during that illness. No unusual ill effects, directly attributable to ionizing radiation, have occurred among Japanese survivors. Whether or not such after-effects will occur among these survivors will have to be answered in the future. There are two possible after-effects from radiation exposure that cannot be fully assessed for many years—effects on heredity and effects on fertility (occurrence of sterility).

Since the demonstration in 1927 that X-rays increased the natural rate of mutations in the fruit fly, there has been much interest in the possibility of similar effects of radiation on man. Mutations have been produced in a variety of plant and animal forms by acute as well as chronic exposure.

Mice bred up to six generations while continuously exposed to 1.1 roentgen daily of gamma radiation from radium gave normal litters and had normal life span. Mice exposed to 8.8 roentgens per day, up to a total dose of 880 roentgens for females and 1,100 roentgens for males, showed no genetic changes in the first generation offspring. Single doses of 1,500 roentgens delivered to the testes of mice have produced gene mutations, both by radiation of the mature sperm present, and by changes in the sperm-forming cells, abnormalities of the feet, retardation of growth, and anemia appeared in the offspring.

From these and other investigations, it is found that the likelihood of parents having deformed children after suffering sublethal amounts of ionizing radiation is very slight.

Genetic Effects

A study of the Atomic Bomb Casualty Commission in Japan deals with possible effects of massive radiation doses on human heredity. Any genetic effects among the Japanese at Hiroshima and Nagasaki will show up in the offspring of exposed people, though possibly not until the second and subsequent generations. No such effects have been observed up to this time. Perhaps 25 years must elapse before reliable information can be obtained about the effects of radiation exposure upon heredity following atomic bomb explosions.

Sterility

Another Casualty Commission study deals with the fertility of the Japanese affected by atomic bomb radiations blasts. Ionizing radiation can cause permanent sterility, but it appears to require about 450 roentgens, the range of the median lethal dose. Temporary sterility occurred among many Japanese, both male and female, but the vast majority of them have returned to normal. It cannot be stated that all returned to normal because investigators do not know how many of them were sterile from other causes before the bombing. Many have produced normal children since their illness.

Cataracts

No significant development of cataracts, a growth which makes the lens of the eye opaque and causes blindness, has been noted among the Japanese as a result of exposure to radiation, although a few have been observed recently. Full evaluation of this hazard must wait on lapse of sufficient time for full development and investigation.

Injury Zones in Atomic Burst

Radiation injury sufficient to cause acute radiation illness will occur frequently for wholly exposed persons, even a mile from ground zero. Unprotected people about 1,300 yards away will probably receive the LD—50 dose of gamma radiation which will cause the death of about half of them. Under 1,000 yards, exposed people certainly will be killed. Neutron radiation would prove lethal up to 500 yards, but all people so exposed would equally receive a lethal dose of gamma rays.

In the following paragraphs of this section, types of injuries to be expected at various distances from ground zero, as judged by effects in Japan, are given in summary. Measurements are of the radius of concentric circles whose center is ground zero, directly below the point of explosion. The effects in these zones will depend somewhat on local factors, especially such topographical features as hills; and the change from one zone to another is gradual rather than abrupt.

Half-Mile Radius

Within a half-mile of ground zero, when the atomic bomb is similar to those used against Japan and detonated about 2,000 feet in the air, the following will occur:

The blast pressure created by the bomb explosion would demolish all structures not reinforced concrete or steel construction. Even buildings of this type would suffer 70 percent destruction. Persons not sufficiently protected by shelter able to withstand the blast undoubtedly would be killed by falling buildings or flying wreckage.

Intense thermal energy generated by the explosion would cause fatal burns to unprotected persons and would start fires in the wreckage.

Because of the concentration of ionizing radiation nearly everyone not protected by earth, steel, or thick concrete would die. The most serious cases would succumb within a few hours to 4 or 5 days after exposure. A second group would develop susceptibility to infection due to destruction of their white blood cells and would die from 4 days to 6 weeks after exposure. Another group would incur multiple hemorrhages and die within 2 to 3 weeks from this cause.

One-Half to One Mile

Structural damage due to blast and fire would be general in the area outside the half-mile circle and up to one mile from ground zero. Residential buildings would be almost destroyed. Only fire and shock-resistant buildings would be immune to any appreciable extent. Casualties from flame burns, blast effects, and injuries due to falling debris and flying glass consequently would be prominent. Second or third degree flash burns would be suffered by people not protected.

Injury from ionizing radiation also would be serious, but as the distance from the explosion point increases, shielding is more effective in lessening of damage from the rays.

One to One and a Half Miles

Beyond a mile, blast damage would still be extensive to residential structures. Fire damage would be extensive in inflammable areas. Flash burns can be expected at this distance. Secondary injuries remain fairly prominent, in the absence of protection by natural or artificial barriers. At Nagasaki, steep hills sharply limited the effects of blast and fire.

Radiation could be expected to be very prominent among the causes of injury up to approximately one and a quarter miles from ground zero. After that distance, such cases drop off sharply.

One and a Half to Two Miles

At Hiroshima the average limit of heavy structural damage was roughly 2 miles from ground zero. The limits of fire damage would roughly coincide with this boundary, except where wind causes wider effects. Flash burns will not be so severe in this area.

Although some Japanese at Hiroshima and Nagasaki who were ill of radiation sickness were reported to have been as far away as 1½ to 2 miles, observations at tests held since then indicate this is impossible.

Over Two Miles

Structural damage due to blast and fire is appreciably lessened beyond 2 miles from ground zero and secondary injuries correspondingly decrease. The maximum distance of a recorded structural damage at Hiroshima, however, was 4.1 miles. Radiation injury and flash burns would be insignificant in this zone.

Section IV. RADIOLOGICAL CONTAMINATION

The radiation dangers discussed so far are those affecting people exposed to immediate injury from the explosion of the bomb. Under certain conditions, radiological contamination could become a dangerous after-effect of the explosion. A high air burst, on a clear day probably would produce no dangerous contamination at all on the surface of the earth—it did not in Japan—and people could enter the area, even directly under the point where the bomb exploded, immediately afterward without danger from this source. This is because most of the residual radiation is swept up into the atomic cloud by the inrush of wind that follows the explosion and is afterward dispersed into the general atmosphere. Most of this radioactive material eventually will fall to the earth but will be so dispersed and diluted that it will rarely, if ever, be hazardous. Heavier particles will fall first, so the greatest out-fall will be concentrated immediately downwind from the explosion point. Here, again, no hazard occurred after the Japanese explosions.

A burst close to the surface, or under water, would increase the amount of contaminated material. When a base surge occurred, heavy contamination might be expected. The amount of such residual radioactivity, and how long it would continue to a degree dangerous to people, would depend upon many and variable factors which are discussed in other reports of this series. Residual radioactivity can be detected and measured by trained teams using Geiger counters and similar devices, and their measurements would determine when and for how long it would be safe to enter a contaminated area.

Residual radiation could come from three different sources—(*a*) Fission products produced by the spilting of atoms in the bomb explosion and deposited on the surface; (*b*) Unfissioned uranium or plutonium so deposited; and (*c*) Materials made radioactive by the radiation emitted during the explosion and either already on the surface or afterward deposited there. The radiation danger during the explosion comes from neutrons and gamma rays. Residual radiation does not include neutrons but comes from gamma rays and from two other types of nuclear particles, alpha and beta. The latter two are chiefly dangerous when emitted by material lodged inside the body.

Alpha particles, which are positively charged helium nuclei containing two protons and two neutrons, have tremendous ionizing power—the factor which causes injuries to people's bodies—10,000 times that of gamma rays. But alpha particles will be stopped by an inch or two of air, by a sheet of paper, or by the surface layer of the skin. Alpha particles are emitted by unfissioned uranium or plutonium but, of these two, uranium is only moderately radioactive and so is not a serious hazard. Plutonium, however, is several thousand times more radioactive than uranium and would be dangerous if lodged inside the body.

Beta particles, which are negatively charged electrons, have 100 times the ionizing powers of gamma rays but can travel only a few yards through the air. Ordinarily, they also can be stopped by a sheet of paper or by clothing, and will penetrate only about a fifth of an inch into the skin, which they affect very much like a burn. Beta particles are emitted, along with gamma rays, by fission products and other materials made radioactive by the explosion. The gamma radiation would be the chief external radiation thread, but would be even more dangerous if the substances were taken into the body.

Radioactive materials can enter the body through the mouth, through breathing, or through a wound. They are particularly destructive when retained in the body for some time. Alpha and beta particles, which can be stopped by the skin, meet no such barrier inside the body. If lodged there, materials that emit these particles can cause serious damage. In evaluating the radiation hazard from these sources, three main factors must be considered:

1. The chemical characteristics of a radioactive element are important, because they determine in what organ the material is likely to be deposited. Materials that behave chemically like calcium will be deposited in bone. Plutonium and strontium are two such elements.

2. If a material is taken in through the mouth, its solubility in body fluids is important. What chemical forms are we dealing with? How much is absorbed from the gastric intestinal tract? Fortunately, most of the fission products are quite insoluble and will not be absorbed in significant amounts. Compounds of strontium, barium, and iodine are the most soluble. Plutonium exists usually in the form of an oxide and only about five-hundredths of 1 percent of the amount ingested is fixed in the body. Swallowed materials must gain access to the circulating blood before they can be deposited in an organ. Thus, even in the stomach and intestines, they are, for all practical purposes, still outside the body as far as radioactive poisoning is concerned.

Once plutonium enters the blood stream, it may be carried to all parts of the body, and much of it is deposited in the liver, spleen, and bone. The most significant points of deposit, as far as serious injury is concerned, are close to the blood-forming tissue in the bone marrow. Here, because of the tremendous ionizing power of its alpha particles it is a constant source of injury to the adjacent tissues.

If it remains in the body long enough, the injury will result in the formation of malignant tumors and severe anemia.

3. The length of time materials remain in the body depends upon their "biological half-life"—the time required by the body to lose one-half the radioactivity by decay and the body's regular processes of elimination. This varies from hours to years with the different elements. In the case of plutonium, the biological half-life is 50 years.

The Plutonium Hazard

The amount of plutonium scattered, after a high air burst of an atomic bomb on a clear day, may be considered inconsequential. Even after a much lower burst, contamination is negligible—one would have to swallow the surface contamination contained in an area of several square yards to get a dangerous amount. The situation probably is not greatly different when atomic bombs are exploded in other ways.

Drinking Water Contamination

Much concern has been expressed regarding the contamination of drinking water. In a high air burst on a clear day, the fall-out of radioactive materials is so small that dilution by the water insures safety. The efficiency of the filtration plants, and the distance of sources of supply from cities are further safety factors. Fission products and fissionable material have a tendency to adhere to any organic material with which they come in contact. They will cling to the banks and the bottom of lakes, to the pipes, and other material to such a degree that it is probable that very little would ever reach the populace. Water containing one-millionth of a curie of fission products per liter is considered safe for drinking. (This means that about one atom in 250,000 billion billion is disintegrating ever second.) Many popular mineral waters contain more than this. Hazards in the case of a storm or base surge remain to be evaluated. Testing for radioactivity is advisable. At Bikini, sea water from a heavily contaminated source was distilled (this is, turned into steam and condensed, not merely boiled) and found safe for drinking purposes.

Inhaling Radioactive Particles

As to the hazard of inhaling particles of matter, the size of the particle is important. The nose filters out almost all particles larger than 10 microns in size (one inch equals 25,000 microns). It will filter out 95 percent of all particles over 5 microns in size. The size at which particles most readily pass from the small air pockets of the lung into the blood stream is about one-half micron. Particles 1 to 5 microns in size may, however, reach the lymphatic system.

At a bomb burst, contaminated particles of this size—the largest only one five-hundred-thousandths of an inch in diameter—ascend rapidly into the atmosphere. If they settle, as on a rainy day, they usually attach themselves immediately to larger particles. The chances of inhaling a dangerous amount of these small particles is small. A combat-type gas mask will filter out almost 100 percent of all such particles.

Contaminated Wounds

If one is wounded while in a contaminated area, the hazards of the situation will depend almost entirely upon the amount and kind of contamination present, and the extent to which the contaminated material is soluble in body fluids. It is difficult to conceive of a situation in which a sufficient amount of contamination would be present to endanger life by this means of exposure, although material introduced into the blood is fixed in the body in a very short time.

Such a wound should be cared for in the same manner as any similar injury in an uncontaminated area. Cleansing with soap and water is particularly important, and possibly excising damaged tissue. The wound then should be closed. Amputation is not indicated.

External Radiation

The chief external radiation hazard in a contaminated area will come from gamma rays thrown off by fission products or by materials made radioactive by neutrons or gamma rays during the explosion. Alpha and beta radiations will be dangerous, chiefly if they come into actual contact with the skin, but it will be necessary to guard against contaminated dust. Filter masks, clothing tight at the wrists, ankles, and neck, and tight-wristed gloves will afford protection against alpha and beta particle contamination. However, material heavily contaminated with beta-emitting material should not be handled, even with gloved hands, since it can cause severe burns. Tongs or equivalent instruments should be used. Clothing should be discarded at the edge of the contaminated area to avoid spreading radioactive contamination.

Thorough soap and water bathing would be a valuable precaution. Bodies that have been exposed to radiation can be safely handled.

Gamma radiation cannot be turned aside by such simple measures as protective clothing, but dense material, such as concrete, can reduce its ionizing effect. Three inches of concrete will cut the amounts of gamma radiation by half, and the customary 9-inch concrete wall used in construction would reduce gamma rays to one-eighth their original potency. However, the gamma radiation from a bomb is measured in thousands of roentgens and, even at distances of 700 yards from ground zero, 20 inches of concrete would be necessary to cut down gamma rays enough to prevent serious radiation injury. Gamma radiation from contamination will not approach the power of direct bomb radiation. The best protection against contamination that gives off gamma radiation is to use instruments to detect its presence and to avoid any dangerous concentration.

What is a dangerous concentration of ionizing radiation? There is a general agreement that, wherever possible, it is desirable to avoid all exposure to ionizing radiation. This, of course, is impossible. Radiation exists everywhere in the world; it comes from radioactive material distributed throughout the earth's crust but its chief source is the bombardment of the earth by cosmic rays from the sky. Human life has always been exposed to this radiation.

In the atomic energy program, a standard has been set, called the maximum permissible dose, which stipulates an exposure which experts believe a man could experience every day in his life without danger of injury. This has been fixed at a maximum of tenth of a roentgen a day, with a weekly maxim of three-tenths of a roentgen. But this standard a plies to daily exposures, a very different matter fro a one-time exposure in emergency. Thus, in t course of a medical study of a disease of the stoma or intestines, a patient may be exposed to some roentgens in undergoing a series of X-ray examina tions. X-rays of the teeth may subject the patie to about 2 roentgens. It is clear that a person m be subjected to a one-time exposure of many tim the daily "maximum permissible dose" without su fering injury.

In emergency operations, a person probably cou be exposed to 50 roentgens of total body radiatio without incurring injury and be able to continue his duties. A person exposed to 100 roentgen might have some nausea and changes in the numbe of blood cells, but most likely would be able to con tinue at his normal duties. Those exposed to 20 roentgens probably would become incapacitated afte the injuries suffered began to take effect—probabl a matter of some hours. In rare cases, as state earlier, 200 roentgens might ultimately cause death

While acute exposures of 200 roentgens and mor will result from atomic bomb explosions, radiatio of this degree rarely will result from residual contam ination deposited by a bomb. The rate of exposure i of considerable importance. A person who receive 600 roentgens in a single exposure within a period o a few minutes will have small chance of survival, bu if a man received only 30 roentgens a day it probabl would take a total of as much as 1,800 roentgens t prove fatal.

Section V. PSYCHOLOGICAL FACTORS IN ATOMIC WARFARE

Since the advent of nuclear explosives in the atom bomb, with its attendant ionizing radiations in massive amounts, unfortunate psychological reactions have developed in the minds of both the military and civilians. This reaction is one of intense fear and is directed against forces that cannot be seen, felt, or otherwise sensed. The fear reaction of the uninitiated civilian is ever evident. It is of such magnitude that it could well interfere with an important military mission in time of war.

Whenever living cells are affected by ionizing radiation, it is detrimental. It must be realized that nature has been constantly bombarding the populations of the world with ionizing radiation since the formation of the universe, by constant exposure to cosmic radiations and to radiations emanating from natural radioactive elements, such as radon and thoron.

This kind of injury must be considered, not standing by itself, but in connection with the total situation, that is, weighed in relation to the objectives in view, both in regard to their importance under the circumstances and their probability of attainment. Unless it can thus be integrated with the whole philosophy of national defense, the atom bomb can prove a liability rather than an asset.

Since it is impossible to stipulate all conditions o experimentation and observation in most of the articles written about radiation for lay consumption, an idea has evolved in many minds that any and a radiation exposure will cause immediate and mysterious injury or death. This reasoning is fallacious, but it also is attractive and has become contagious.

The problem of radiation injury is not one which can be easily simplified. In fact, over-simplification of this danger may be the cause of a situation such as we are combating at this time. It seems desirable to explore radiation hazards more fully in relation to other hazards which are considered more common and acceptable.

The permissible radiation dose is 0.2 or 0.1 r per day, or 0.3 r per week. It should no longer be called the "tolerance dose" for no amount of radiation should be tolerated without good reason. One is willing, however, to name a dose so small that a person might be exposed to it every day of his life and suffer no observable injury nor shortening of his life span.

When one is dealing with radiation technicians or with industrial workers who are exposed to this hazard daily in their life's work, one can easily see how the maintenance of exposure at or below this level is a very desirable thing. Day by day contact with radiation or radioactive materials demands that a low limit of exposure be adhered to, if one is to avoid late complications of such chronic trauma. Similar occupational hazards exist in all branches of production—noxious gases and dust to the coal miner, the steel worker, and the chemical worker. It has been known for years that if a miner is subjected to small amounts of dust containing silica that he eventually will develop silicosis, frequently complicated by tuberculosis, and a fatal termination. For this reason, methods of counting and analyzing dust have been perfected, and forced ventilation systems have been established to minimize the danger. This does not mean that if an individual makes a one day visit to a mine and inhales 100 times the daily minimal allowance for miners that he will develop silicosis. This tolerance limit has nothing in its definition which refers to acute exposure. Neither is the 0.1 r per day tolerance limit related to acute exposure in radiation.

The total body dose of radiation received as an acute exposure is known from therapeutic experience to vary with the patient. This and the lethal dose for man have not received the same attention from rule-making bodies that the "permissible dose" has had. We may take 450 r as the median lethal dose.

Going further down the scale, one may consider a limit of 200 r, which may cause radiation sickness in 50 percent of human subjects when delivered as an acute dose of total body radiation. Some subjects may be quite sensitive to radiation and others quite resistant, so it is difficult to calculate the precise effects to be expected.

It is not unusual to subject a patient to multiple X-rays of the skull, spine, long bones, gastro-intestinal tract, kidneys, sinuses, etc. in a relatively short space of time, thus subjecting him to a dose of radiation which may well approach 25 r. These procedures are not done without purpose and the benefit from the information gained outweighs all fear as to the possible injury from radiation. Full body radiation in doses of the order of 25 r to 100 r have been given to patients for treatment of various conditions. Again, these exposures are prescribed for a purpose which outweighs the fear of radiation injury.

It is not intended to underestimate or understate the radiation hazard but, from a military standpoint, the physical danger must be evaluated against the objective to be gained.

War is fought with the knowledge that men will be killed. Campaigns are planned with expectation of losing so many thousand men. If you call these "acceptable hazards" then it obviously is not wise to treat radiation hazards very much differently. If acceptance of radiation hazards will lessen the other military hazards, then, that is what one should accept. However, this can be done only if the attitude of the men exposed is psychologically similar toward the two types of hazards. If they are going to be as much terrified by the knowledge that a recent atom bomb explosion has contaminated the ground they are walking over, as they would be by seeing one in ten of their buddies fall by machine gun fire, one cannot apply the "ideal" solution. What is dominant for actual percentage survival is the resultant of all the actual hazards but, for battle discipline and military effectiveness, the dominant measure is not the hazard itself but the soldiers' estimation of the hazard.

Men at war suffer many hazards, acute and chronic, besides bullets; malaria, venereal disease, exposure to cold and wet, starvation, etc. Some of these, for example, venereal disease, are underevaluated by the soldier. Others, for example, filariasis, are grossly over-evaluated. At present, radiation is perhaps over-evaluated most of all, partly due to our great care in Operations Crossroads. That operation was conducted at the peacetime level of safety to personnel. Unless we had openly proclaimed immediate danger of war, the military level for hazardous training programs such as we had actually adopted during the war, using live grenades and live ammunition in the machine guns, was not tolerable at Bikini. It must be emphasized that acceptable hazards in a peacetime operation cannot be adhered to in war time.

Psychological training for the military level of acceptable radiation hazard is possible and should be prosecuted, even though operation field training does not permit this to be accomplished at the present time.

We hear much about sterility as a result of exposure to ionizing radiation. It must be borne in mind that sterility results only from a large dose of acute radiation, or from smaller doses over a long period of time—a matter of years. Sterility also results from other accepted hazards encountered in war, venereal disease is one of the foremost causes of sterility. We are aware of hundreds of paraplegics resulting from spinal fractures, gun shot wounds of the cord, etc., during the last war who are not only sterile but impotent. Leukemia may be another late result in casualties from repeated radiation, but amoebic dysentery and schistonomiasis carry a great delayed hazard, and so does the effect of beri beri, which was so prevalent among our prisoners of war.

In August of 1946 a large number of Japanese who had recovered from radiation sickness were examined and found to be perfectly normal and were handicapped in no way toward pursuing their way of living. Such is not the case with thousands of our soldiers who participated in "conventional" warfare in World War II; they are handicapped by loss of limbs and eyes. Neither is it true of many of the Japanese who received no radiation injury but received severe burns and traumatic injury as a result of the bombing. It has been estimated that from 5 to 15 percent of the deaths at Hiroshima and Nagasaki were due to radiation. Why then concentrate on the 15 percent and forget the 85 percent?

The atomic bomb was developed as a blast weapon of war and strategically so used. The radiation effect was never considered to be the prime component of its effectiveness. The destruction attendant to the blast, heat, and secondary fires was paramount. In Japan there was no significant "poisoning" of the ground by fission products or induced activity from neutron capture; yet many believe that the bomb is primarily a weapon which destroys by mysterious radioactivity.

It seems that local defense agencies in our cities which are preparing for defense ag atomic bomb attack are thinking only of ra Invariably they ask, "Where will we get counters?" Geiger counters are not their only lem—fire-fighting equipment is many times m portant, as well-organized rescue squads. have been told that we will not be able to go bombed city and rescue the injured." Hiroshi Nagasaki disprove this. The residual radiation an air burst bomb is insignificant. The sig prompt radiation occurs in a matter of micro and does not extend beyond a 2,000 yard di Immediately after such a detonation, such as shima or Nagasaki, it is perfectly safe to en bombed area and rescue the thousands whose in will be such that they will not be able to walk. evacuation of these injured is effected, thousands be burned to death by secondary fires. Such w case at Hiroshima and Nagasaki. But how abou underwater or ground burst? In such cases, cert the residual radiation hazards would be inc many fold, but the blast and fire hazards an prompt radiation hazard would be proportionate creased, and most probably the total number o ualties would be less.

If one is to live with the atomic bomb and have to use it again in the defense of our way o ing, a practical attitude must be acquired not toward its efficiency or limitations as a bom also toward the possible effects and limitations o "mysterious" radiation. It is necessary to recog that the casualties caused by the blast and burns this weapon will be many times greater than deaths caused by radiation. And, further, the roneous idea that the rescue work of the injured be impossible, due to residual radiation, must be pelled.

It is of the utmost importance that we recogn that the radiation hazards are additional hazar They only add to the complexity and perhaps eve the severity of the other hazards of total warfare Therefore, we must not and cannot concentrate o this phase of atomic warfare to the detriment of ot defensive preparations. Rather, we must know a understand the facts about ionizing radiations if are to survive the other dangers.

A resumé of the personnel effects of radiolo hazards is shown in table III.

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Table III. Resumé of Radiological Hazards

Particle	Approximate range in air	Comparative penetrating power	Action on human body	Protection and detection
Alpha	3 inches	1	Internal Hazard only; very high ionizing ability.	Clothing, gas mask, any thin material like paper, and DISTANCE. Field detection possible.
Beta	26 feet	100	Mainly internal hazard; may cause skin lesions; high ionizing ability.	Heavy clothing, gas mask, any thin material like paper and DISTANCE. Field instruments available.
Gamma	Several hundred yards	10,000	External hazard, moderate ionizing ability.	Very heavy, thick materials like lead, deep dugouts, and very thick concrete. Easily detected with the various types of field devices available.
Neutron	Not lethal beyond 600 yards	Approximately 10,000	External hazard; induces radioactivity; very high ionizing ability.	Protection required intermediate between Beta and Gamma. Field detection not available at present.

1. **INTERNAL HAZARDS**—(Radioactive fragments as fine dust or small pieces which can get into the body by mouth, nose, or cuts.) Decontamination: Induce vomiting, cause cuts to bleed and wash, take soap showers using plenty of water and giving special attention to hairy regions. Check with moniter, and re-shower if necessary. Change clothing completely. Carry nothing out of "HOT" area. Conduct in Contaminated Area: Cover mouth, nose, and ears, or wear gas mask, keep exposure time to minimum, and DON'T eat, chew, smoke, or kick up dust.

2. **EXTERNAL HAZARDS**—(Particles which can penetrate skin and clothing and cause damage while personnel are near a source of radiation.) Decontamination: Get away from source and stay away from it. Don't carry anything out of "HOT" area, even the dust that is in your clothing, and on your skin (see internal hazard). Conduct in Contaminated Area: Keep exposure time to minimum. Work quickly and efficiently—in relays, if possible. Wear pocket dosimeter and film badges.

3. **DISPOSITION OF CONTAMINATED MATERIAL**—*a.* Remove to uninhabited area and mark area clearly. *b.* Wash with solution of Hydrochloric and Citric acid; or *c,* Wash with G. I. Soap and lots of water; or *d,* Remove surface by chipping, paint remover, sand blast, etc.

4. **PROTECTIVE WARNING DEVICES**—Pocket dosimeters, film badges, ionizing chamber survey meters, Geiger Counters.

5. **RADIATION SYMPTOMS, COMMON TO ALL TYPES OF RADIATION**—Nausea, vomiting, general lethargy, hemorrhages, diarrhea, loss of hair, skin rash, destruction of the blood producing organs (mainly by internal hazards), etc.

6. **MILITARY TOLERANCE DOSAGE**—No tolerance dosage for internal hazards has been established since minute internal dosage may be fatal. In peacetime the maximum allowable tolerance dosage for personnel working in or near external hazard radiation is .3 roentgen per week. (25R—the smallest dose measureable by medics, 200 R—50 per cent sickness, 450 R—100 per cent sickness and 50 per cent deaths, 700 R—100 per cent deaths. These figures are highly theoretical and are used here only to show probability of sickness and death demonstrate safety of military tolerance dosage.

POTENTIAL STRATEGIC AND TACTICAL USE OF ATOMIC WARFARE, OFFENSIVE AND DEFENSIVE

The use of nuclear power in war has been, and will continue to be, discussed by nearly everyone in the country today. A few speak from experience; some with authority; many with little real understanding of the enormous implication and problems involved in this type of warfare. Whether this free discussion is good or bad, in a democracy like ours and within certain limits, it must be tolerated.

Much material on this subject has appeared in print. Here, again, a wide range of opinions is expressed, some based on very unrealistic premises. Some present an extremely careful evaluation of the situation; others indicate little deep thought. While most published material has been written by nonmilitary people, some material on the subject has been prepared by members of the military establishment.

All of this emphasizes the important concern and vital interest which both the public at large and the military in particular attach to the subject of atomic warfare.

In the time allotted for this topic, not much more than a general over-all view of some of the most fundamental aspects can be provided. Specific applications of principles presented are responsibilities of command. Attention is invited to the fact that when principles such as are discussed in this chapter are applied to a specific military operation with its concomitant logistics data, the security classification immediately would become higher.

To begin with, it must be remembered that basically the primary function of any military operation is to overcome the armed resistance of the enemy and to take full command of the situation as a result of offensive operations. It also is basic that this operation be accomplished with a minimum loss of men and equipment. This concept is fundamental, regardless of the type of weapons used. The means to be used, the length of the operation, the tactics to be employed, and the maximum loss of men and equipment that can be expected by the attacking force all are determined by the importance of the objective to be attained. The military principles and procedures used to resolve these problems for a particular operation are discussed in the various armed service schools and are familiar to officers of the armed services, and will not be reviewed here.

Keep in mind that in delivering an atomic bomb attack on a city, for example, with its resulting widespread destruction of property and lives, and taking over of such a ruined city would not be an unmixed blessing. The victorious forces would have to assume command, restore much of the facilities that were destroyed, and furnish the immense medical care required. This puts an exceedingly heavy burden on the offensive force. The factor of diminishing return must be considered in the widespread use of high energy atomic bombs against large cities in enemy territory, especially where the control of the city is not important to field operations.

This principle of delivering an atomic bomb attack on a city does not rule out, however, the possibility of using the bomb on certain strategic and key cities. The partial destruction of a city or installation in enemy territory engaged in large-scale production of war matériel would certainly be worth an atomic bomb. Large shipping centers; important concentrations, such as the Chief Military Command; the seat of a national government; or other great organization centers that are directing the war effort would be vital targets, upon which the expenditure of an atomic bomb of high destructive power would prove of great value. Staff studies of the relative importance of demolishing key war-making establishments of the enemy, as balanced against taking over partially ruined cities in which communications, highways, water supply, and electric power systems have been demolished, must be made.

The atomic bomb is not the only type of instrument that can be employed in atomic warfare. Two or three years ago, when the technical knowledge of nuclear power and techniques of the manufacture of raw materials that go into atomic bomb construction were very limited, the military planned in terms of atomic bombs only. Since then, vast improvements in the various processes involved in the manufacture of the ingredients of the bomb have changed the picture. Material that was considered critical and scarce at that time is now available in fair quantities.

The availability of material for atomic warfare changes the military planning considerably. The planning can shift from strategic to tactical, and it is now apparent that the military establishment can think in terms of using atomic bombs for tactical use, as well as for strategic use. From this point of view, the field and local commands would become directly involved in atomic warfare. Such commands must guide themselves accordingly, since equipment that can be used for tactical purposes becomes a potential weapon for all units of the Army.

An important point for local commanders in connection with the shift from strategic to tactical use of atomic warfare is the large increase in the number of trained military personnel becoming available. Even with large quantities of bombs, an insufficient number of trained personnel would seriously diminish the effectiveness of any type of war machine for tactical purposes.

With an increased number of trained personnel and larger number of atomic bombs available, it becomes possible to use this type of warfare on smaller and less important targets than under the strategic plan of atomic warfare. It is quite certain, however, that atomic bombs will be used only after careful selection of important targets. They will not be used indiscriminately. In common with any device in limited supply, it will always be a question of allocation to targets which will be of greatest effect in advancing our over-all military position.

The limited supply of atomic bombs likely to be available to both sides is the key to determining the defensive measures to be used against an atomic bomb attack. The tactical plan for landing an amphibious force to take a beachhead is an example of this principle. For example, it is conceivable that in planning for a concentrated attack, the forces would be constrained to assemble in a very dispersed formation prior to the engagement. They would mass together at the desired point of pressure such as a beachhead, just long enough to accomplish the mission and then disperse again. Concentration of force would have to be held at a minimum. This dispersion would reduce the opportunities of the enemy to use the bomb effectively. Under these conditions, such great operations as the Normandy landing probably would not be attempted.

It is to be noted that thus far the discussion has centered around the use of atomic or nuclear energy in the form of bombs of considerable size and explosive power. It is but a short step from the use of single atomic bombs to the concept of dispersing radioactivity in small quantities over wider areas. This leads, naturally, to the concept of contaminating large regions for strategic or tactical purposes. For example, suppose the attacking force does not consider a certain area important enough to occupy, but, at the same time, does not want the enemy forces to occupy the area. The dispersion of radioactive material could be used to prevent continuous enemy occupation. In large scale operations, where it is desirable to by-pass smaller areas which might fall into enemy hands, these areas could be placed in a radiologically contaminated condition so that, while they would not be used by the attacking force, they also could not be used effectively by the enemy forces. Thus, a type of atomic warfare which offers an additional tactical maneuver, similar to that used in chemical warfare to deny an area to the enemy, becomes feasible. Its possible use in a future war therefore should be considered by personnel engaged in preparation of plans and in command positions.

Thus far nothing has been said about how the atomic bombs are to be delivered to intended targets. Delivery by air in specially modified aircraft is most likely. Increased vulnerability of aircraft to enemy action might make it necessary to consider other methods of delivery. Thought has been given to the use of submarines for the transportation of the bombload. Actually, delivery of the bomb might be accomplished in several ways. It might be fired from the submarine, when surfaced near some coastal city, or the submarine might deliver it in the harbor area underwater.

Delivery of the radioactive contamination type of weapon might be done in several different ways. The use of aircraft for dispersion, the use of guided missiles with the warhead containing radioactive material, or the use of special drone planes all are possibilities in connection with tactical and strategic planning. Another important consideration in the use of atomic warfare is that of the logistics involved in the production of such equipment. If the production is to be done during wartime, when manpower and material must be siphoned off from the war effort, evaluation must be made of this effort as compared with the possible result to be attained by the production and delivery of atomic weapons. On the other hand, adequate defense against tapping the manpower, resources, and materials during a national emergency would be to stockpile such material during peacetime when labor and material are not at a premium. Long-range staff planning on the stock piling of atomic bombs and other radiological weapons of war has no doubt been done. It is suggested that military personnel responsible for staff and unit planning make themselves acquainted with such plans as may now be available to them at their respective commands. Those responsible for training should see that Command problems, practical experiences, and troop training maneuvers include various phases of radiological warfare.

One point should be emphasized. The intensity of the radiological contamination, thought to be so great when atomic bombs were first revealed to the public, is found to have been grossly exaggerated. The radiation is not nearly as great as was at first supposed. Much medical research on the effect of radiological exposure on living tissue in animals has been published. These results indicate that living healthy tissue can tolerate considerably more radiation than was at first supposed. It can be anticipated that the radiological exposure dosage permitted under wartime emergencies will be very much higher than peace time civilian laboratory tolerance dosages. The health physics standards for laboratory workers, however, have been set at an extremely safe margin using a safety factor of several hundred times. And furthermore, the laboratory dosage is set for an anticipated long exposure of many years, while the military is set for, at most, a few days.

Inasmuch as radioactivity is not detectable in any way by our senses until too late, recourse to instruments must be made. In addition, military intelligence will certainly be involved in the strategic and tactical problems of anticipating and counteracting enemy radioactive warfare.

CHAPTER 6

RADIOLOGICAL DEFENSE TECHNIQUES AND EQUIPMENT, DECONTAMINATION

Section I. RADIOLOGICAL DOSAGE VS. INTENSITY

A careful distinction must be made between the expression "radiological dosage" and the "intensity of radiation." Although these two physical quantities are definitely related, they carry distinct differences in meaning. Dosage infers the total amount of radiation received regardless of the period of time involved. Intensity of radiation, on the other hand, is an indication of the rate at which the dosage is received. The word "dosage" is synonymous with "exposure" used in photography. Exposure includes both the intensity of the light as well as the length of time the shutter is open. In the same way, dosage involves both the intensity of the radiation and the length of time one is exposed to that intensity of radiation. The two quantities are related mathematically as follows:

Dosage = Intensity × time

D(milliroentgen = I(milliroentgen/hour) × t(hours)

Another analogy between radiological dosage and intensity of radiation would be to consider dosage in terms of the total number of pills which a patient would take and intensity of radiation as the number of pills taken per hour.

It must be remembered that the permissible dosage in time of an emergency is a command decision. It may go to five, twenty-five, or even fifty roentgens per day. Expressed in milliroentgens this is 5,000, 25,000 and 50,000 milliroentgens every 24 hours.

A quick thumb rule formula to determine the length of time one may remain at a particular spot when the intensity of radiation is read on a field survey meter is known as:

$$t \text{ (in hrs)} = \frac{\text{permissible dosage (mr)}}{\text{meter reading (mr) (hr)}}$$

This formula can be computed mentally and is useful when the daily permissible dosage, set by the command, is known, and a meter reading is obtained at the particular spot in question. For example, if the command has set one roentgen per day as the permissible dosage and the meter reading at same spot reads 200 milliroentgens per hour, simply divide 1,000 by 200 and obtain 5. Thus, one may remain at this spot for five hours and still be within the permissible dosage established by the command. Although the permissible dosage as set by the command usually will be expressed as a whole number, it is simply necessary to read the meter and divide mentally into the permissible dosage expressed in milliroentgens.

Section II. INSTRUMENTS FOR DETECTING RADIATION

Fission products and unfissioned bomb material continue to emit radiation for varying periods of time after the explosion which might, under some circumstances, constitute a real health hazard. Obviously, it is important to detect the presence of these radiations and to measure their intensity. Instruments used for this purpose are called *radiac* instruments (coined from *ra*dioactivity *d*etection *i*dentification *a*nd *c*omputation).

At present, most field types of radiation-detecting instruments make use of two effects of radiation—darkening of photographic film and ionization of gases. The photographic effect is used in the film badge (fig. 22); the ionization effect is used in the familiar Gieger-Mueller types of survey meters (fig. 19), the ionization-chamber type of survey meter (fig. 20), and the pocket dosimeter (fig. 21).

The instruments using the principle of ionization will be discussed first. The atoms or molecules of a gas under ordinary conditions show no electrical charge. A gas is made up of countless numbers of atoms or molecules, almost all of which are electrically neutral. In the presence of radiation, however, the atoms assume electrical charges. If an external electrical field is applied, these electrified atoms (ions) will drift in a certain direction, thus constituting an electric current. Such a current is known as an ionization current.

How does radiation cause atoms to assume an electric charge? Normally, the negatively charged orbital electrons of an atom just balance the positive charge on the nucleus of the atom. Thus, externally the normal atom exhibits no electrical charge. If, however, an orbital electron were removed from a normal atom, this atom would exhibit to the external world an electrical unbalance of one positive charge and this atom would be positively charged. Note that by removing one electron, which is itself negative, two charged particles are created—a negatively charged particle, the electron; and a positively charged particle, the electrically unbalanced atom. These two charged particles are called ions, and the process of formation is called ionization. Thus, whenever an atom is ionized, a pair of ions is formed. The mass of the negative ion, and removed electron, is much less than the mass of the positive ion, the electrically unbalanced atom.

Figure 19. G-M type survey meters.

If a voltage is applied across a volume of gas in which some of the atoms have been ionized, the voltage will cause the much lighter negative ion to move faster in one direction than the same voltage will cause the much heavier positive ion to move in the opposite direction. Since the positive ion moves so much slower than the negative ion, only the effects of the faster negative ion will be considered here in describing the action of instruments.

The removal of an orbital electron from a neutral atom may be accomplished in many ways. However, the action of the radiation emitted by radioactive substances in producing ions is of utmost importance because it offers a means of detecting its presence.

To understand more fully the action which ionization plays in the operation of certain types of radiac instruments, consider the ideal situation shown in figure 23. This ideal circuit consists of the ionizable volume of gas, some type of indicator to show the amount of ionization, and a source of voltage which can be varied from zero to about 1,000 volts. The relationship between the voltage applied across the

Figure 20. Ionization chamber type field survey meters.

chamber and the response produced as recorded by the indicator is shown graphically in figure 24. In this graph the applied voltage is indicated along the horizontal axis while the number of ions collected is shown along the vertical axis.

Assume now that the volume of gas is being irradiated by a constant source. To begin with the voltage is set at zero. The radiation emitted by the radioactive source will produce ions in the chamber, but inasmuch as no voltage has been applied to the chamber, the positive and negative ions move about in no specific direction and, as a result, many of the positive and negative ions recombine, forming neutral atoms again. No indication is thus obtained on the meter.

When a small voltage is applied, the ions that are present will drift in such a way that the negative ions are urged to the positive electrode (anode) while the positive ions are urged to the negative electrode (cathode) of the chamber. The voltage next is increased by a small amount. Some of the negative ions will drift toward the anode, thus causing the indicator to show a feeble flow of current. Increasing the voltage increases the number of ions formed and the speed with which they drift toward their respective electrodes, and this, in turn, increases the amount of ionization current which is recorded by the meter. Gradually increasing the voltage causes more ions to migrate to the electrodes, contributing to a larger increase in the ionization current (region A, fig. 24). This effect continues until a point is reached at which no further increase in current is noted when the voltage is increased. This means that all the ions produced are collected at the electrodes as fast as the radiation produces them. The voltage at which this takes place is known as the saturation voltage. Ionization chamber type radiac instruments are operated at a voltage which will insure saturation for the useful life of the battery. This effect is called the ionization chamber region (region B, fig. 24). Note that in the ionization chamber region only the ions formed originally by the radiation contribute to the ionization current as recorded by the meter. Figure 25 shows the essential features of the ionization chamber type

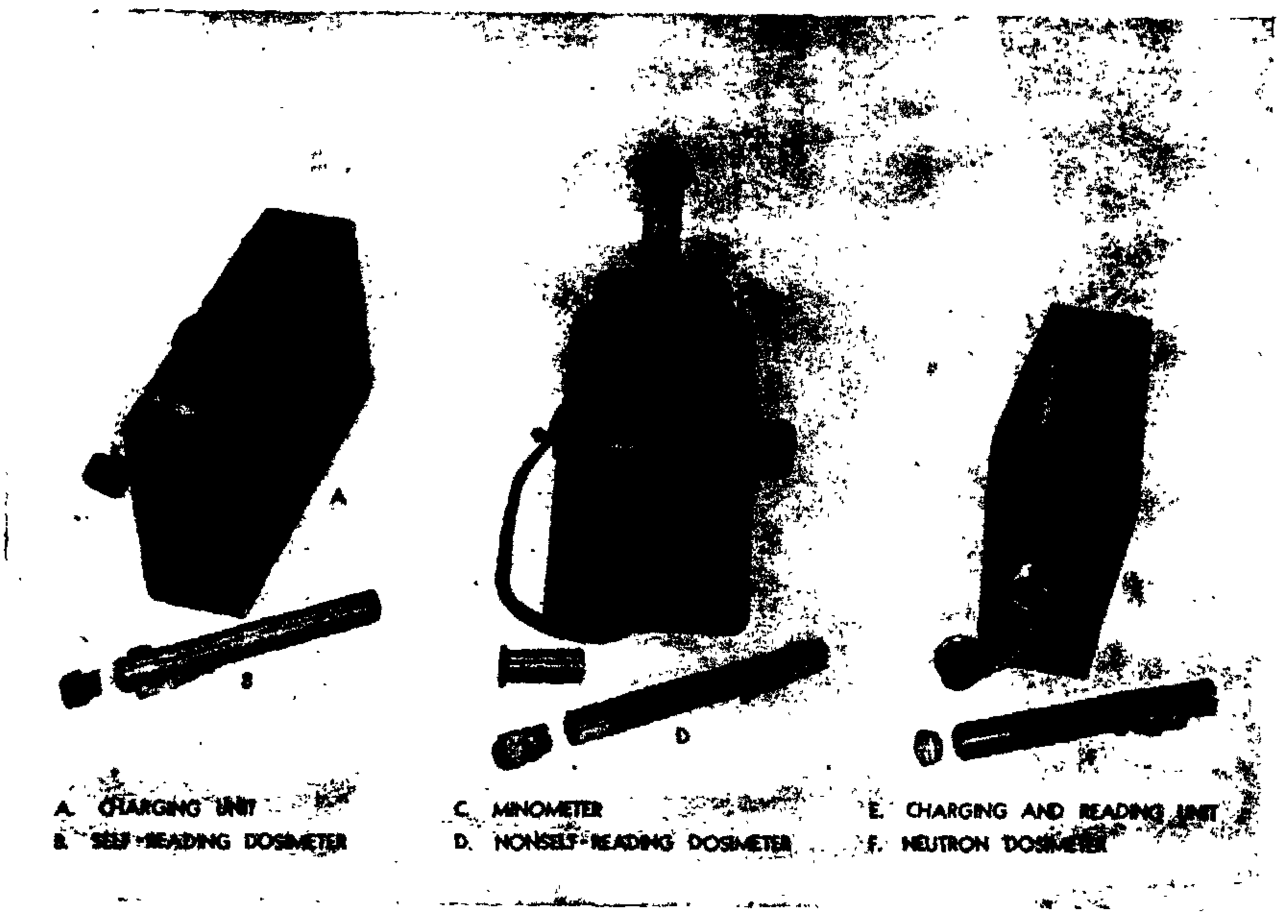


Figure 21. Pocket dosimeters and auxiliary charging units.

instruments. Further small increases in the applied voltage cause no increase in the ionization current produced. This is represented by the flat portion of the curve. Since the ionization current is extremely small, a very sensitive electronic amplifier must be used to magnify the effect which is recorded on the indicating meter (calibrated to read in milliroentgens per hour).

Beyond the ionization-chamber region, increasing the voltage a little more causes the ionization current to increase. It is obvious that some new effect now is taking place within the chamber. At this higher voltage, *the negative ions are attaining quite high speeds* at which the electrons have sufficient energy to knock out electrons from surrounding neutral atoms. It is these secondary electrons which now are contributing to the previous effects. As the voltage is increased still more, the number of secondary electrons increases. These, in turn, acquire enough speed to ionize more neutral atoms. All contribute to the ionization current recorded by the meter (region C, fig. 24).

The production of secondary electrons caused by collisions of the primary electrons is known as gas amplification. The amount of gas amplification depends upon the applied voltage and increases rapidly with voltage. At low gas amplification there is a region called the proportional region (region C, fig. 24). At present, this is not important for field survey detection.

A voltage is finally reached where the energy of a single electron is so high that it will "trigger off" the whole series of secondary electrons. When the applied voltage is so high that a single electron produces many avalanches of secondary electrons and thus, in effect, "fires" the chamber, the gas is operating in the Geiger-Mueller region (region D, fig. 24). Any radiation which will initiate a single ion within the volume of the gas is sufficient to "trigger off" the

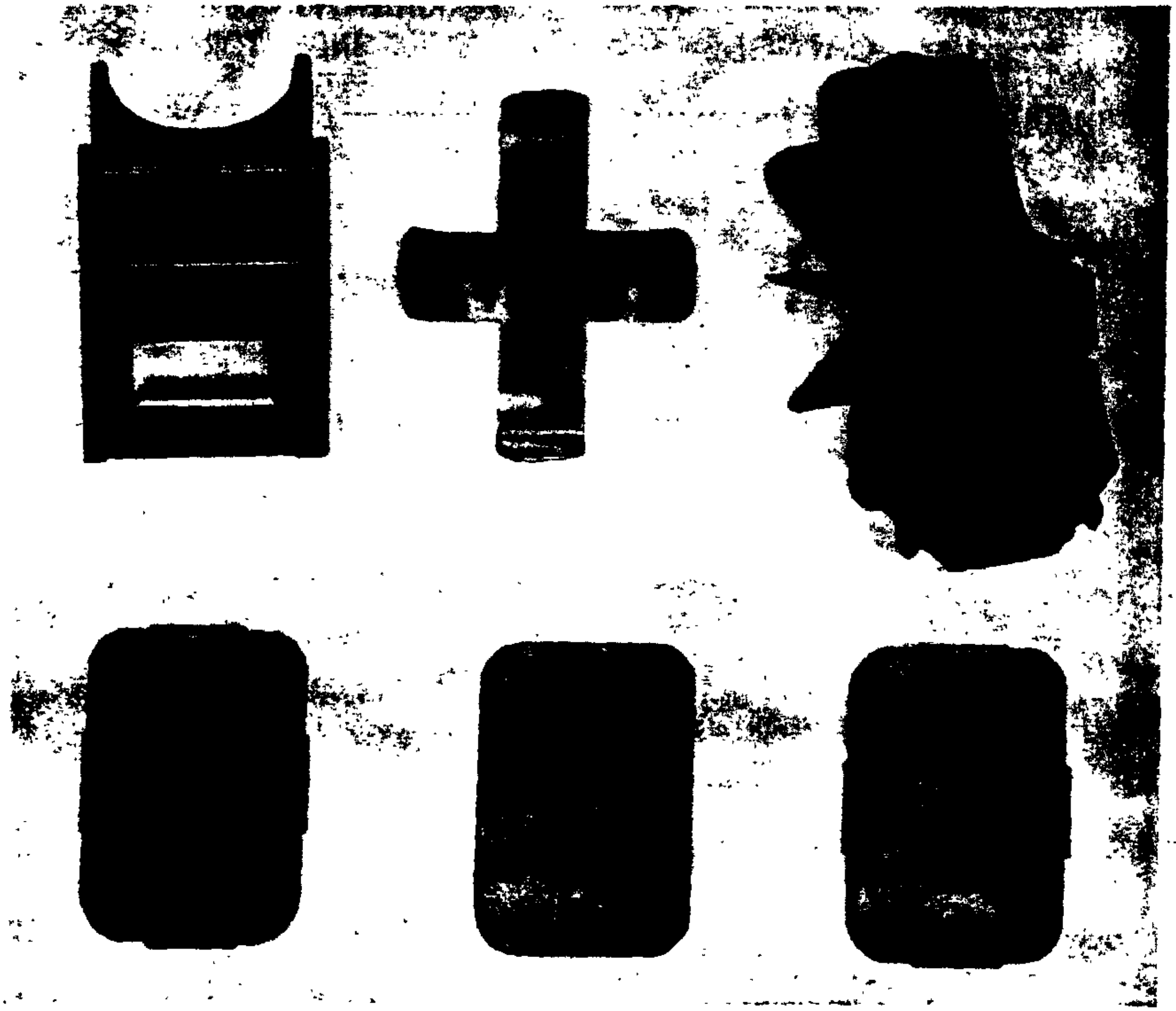


Figure 22. Film badge and film badge holder.

reaction. Immense numbers of electrons move to the anode and a large ionization current flows.

While the gas is in this condition, it is unable to respond to any other radiation. Since radiation occurs as a series of random shots rather than as a continuous flow, it is necessary after each "firing" that the G-M tube be returned to its original receptive state as soon as possible and be ready to respond to the next incoming "shot" of radiation. Practical Geiger-Mueller tubes and their associated electronic circuits are so constructed that the inoperative time is minimized. From this it is obvious that the Geiger-Mueller type of instrument, while exceedingly sensitive to very low intensities of radiation, becomes inoperative for higher intensities. As its upper limit of response it will go into continuous discharge, a condition which gives meaningless readings on the meter and which is detrimental to the tube. Geiger-Mueller tubes often are referred to as counters, inasmuch as they are alternately operative and inoperative, giving rise to pulses. The individual impulses may be recorded by an auxiliary device such as a head set, or they may be intergrated and recorded on a meter. Figure 26 indicates the essential features of a G-M type of survey instrument.

From the above discussion it can be seen that the Geiger-Mueller type and the ionization chamber type of instruments have certain specific limitations. The ionization chamber type instrument is not suitable for very low intensities but is exceedingly good for high

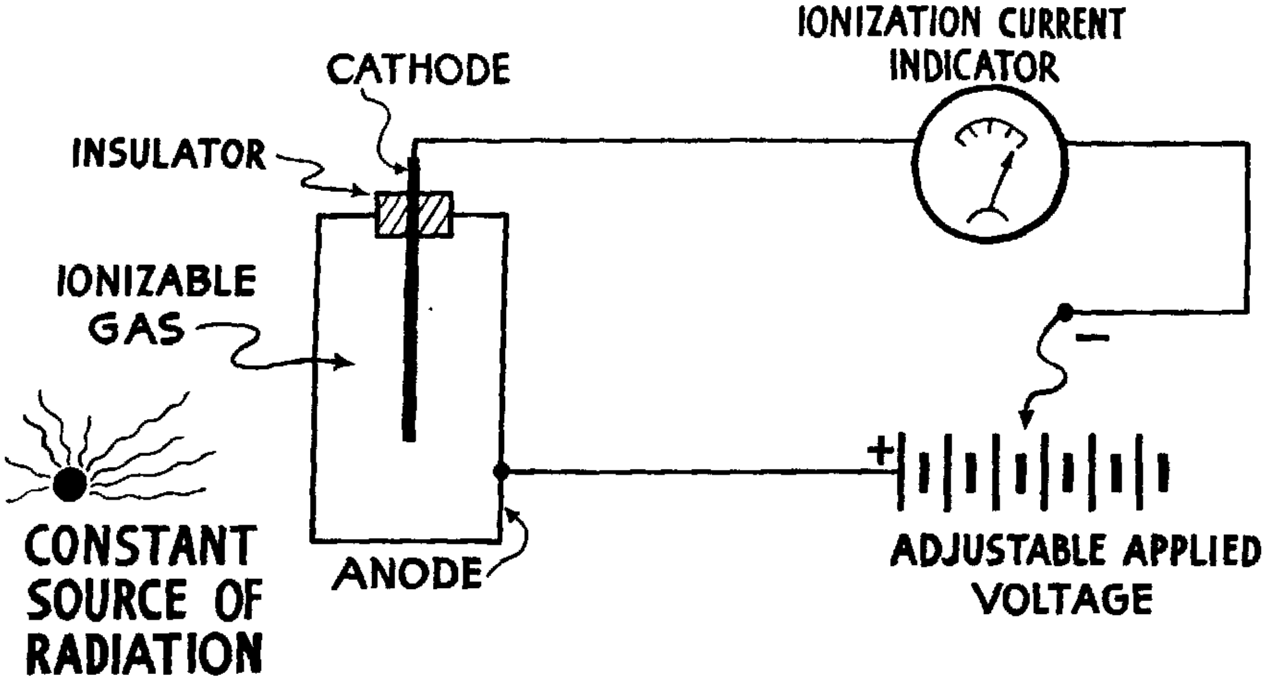


Figure 23. Ionization effect versus applied voltage—idealized circuit.

intensities. On the other hand, the Geiger-Mueller type of instrument is limited to intensities of radiation below about 50 milliroentgens per hour, but it is exceedingly responsive to very low intensities. No commercially available instruments completely meet the military requirements for field-type work, and an extensive research and development program is directed toward improved instruments.

To protect personnel against radiological hazards, it is not enough to know the intensity of the radiation.

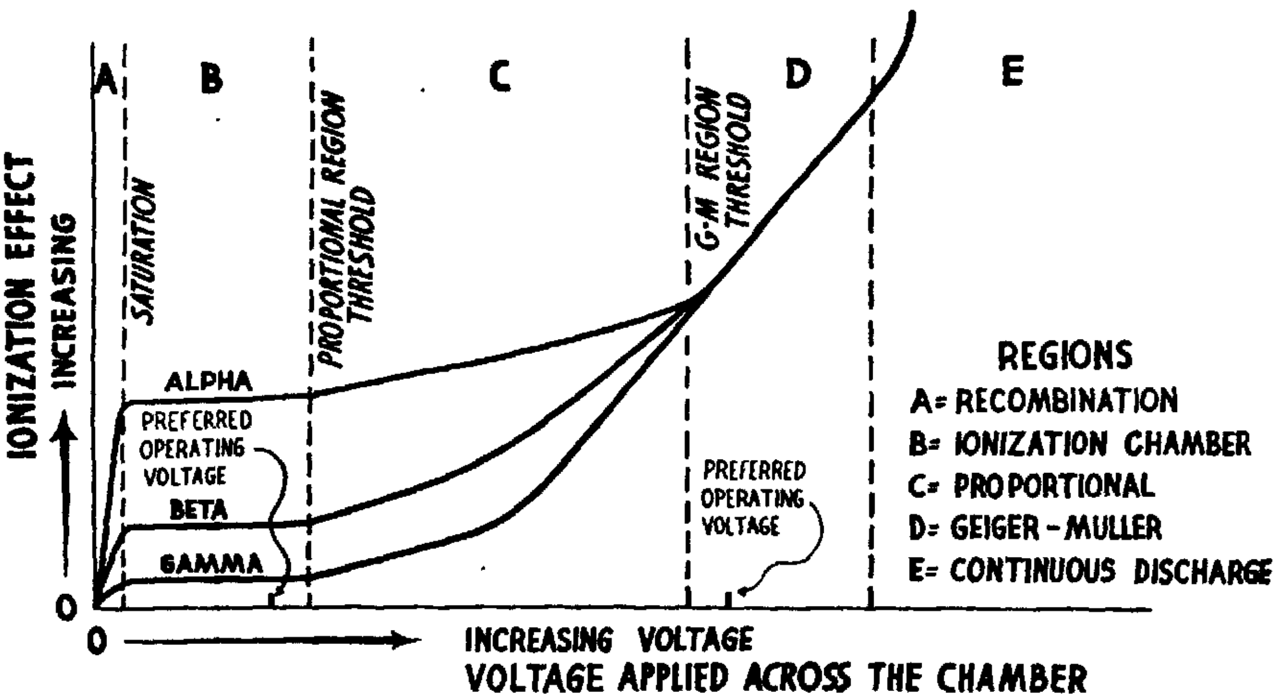
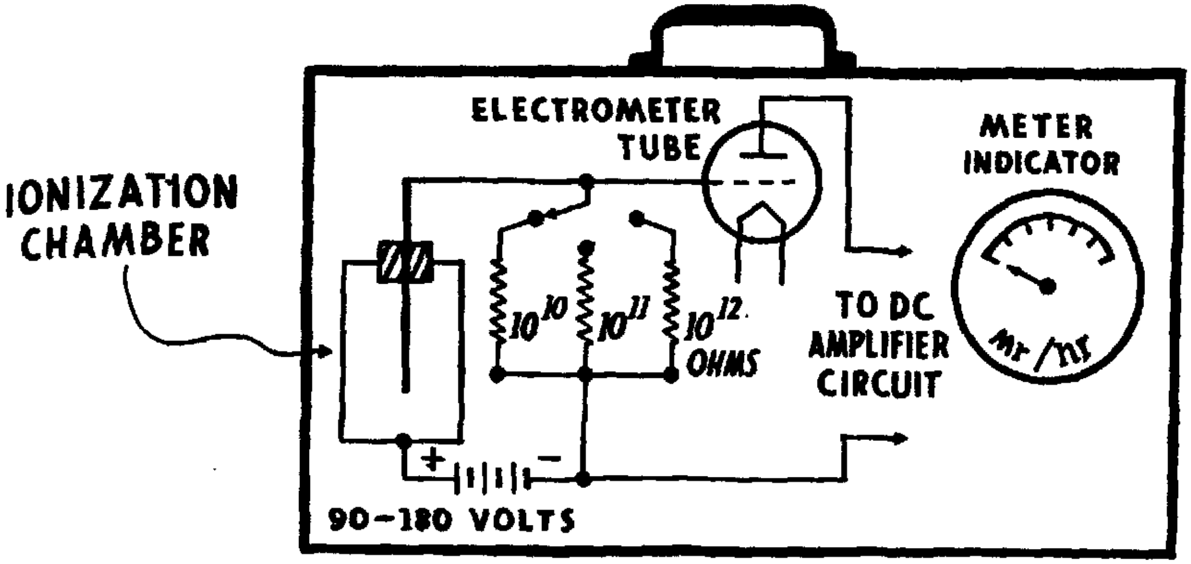


Figure 24. Ionization effect versus applied voltage.



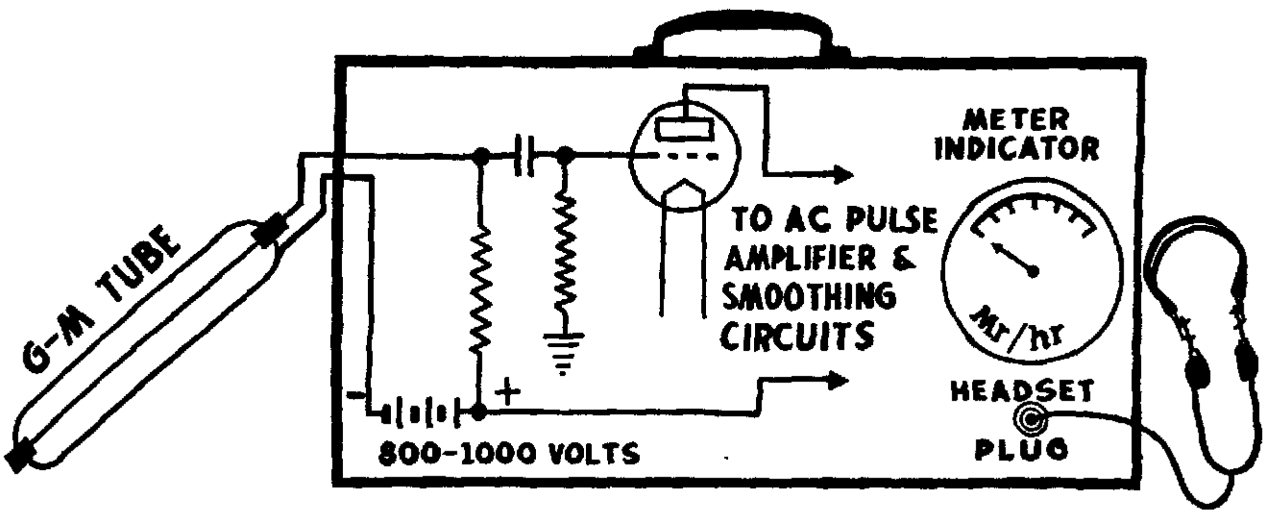
USUAL RANGE OF AVAILABLE INSTRUMENTS 25 TO 50,000 MILLIROENTGEN PER HOUR

Figure 25. Basic principle ionization chamber type field survey meter.

For a complete record, it is important to know the total exposure or dosage which an individual receives while in a radiation field. Radiological exposure or dosage depends on the radiological intensity and on the length of time of the exposure (fig. 27). Quantitatively expressed, the exposure of roentgens is—

$$D = I \times t$$

where t is time in hours of exposure and I is in-



USUAL RANGE OF AVAILABLE INSTRUMENTS 0 TO 50 MILLIROENTGEN PER HOUR

Figure 26. Basic principle G-M type field survey meter.

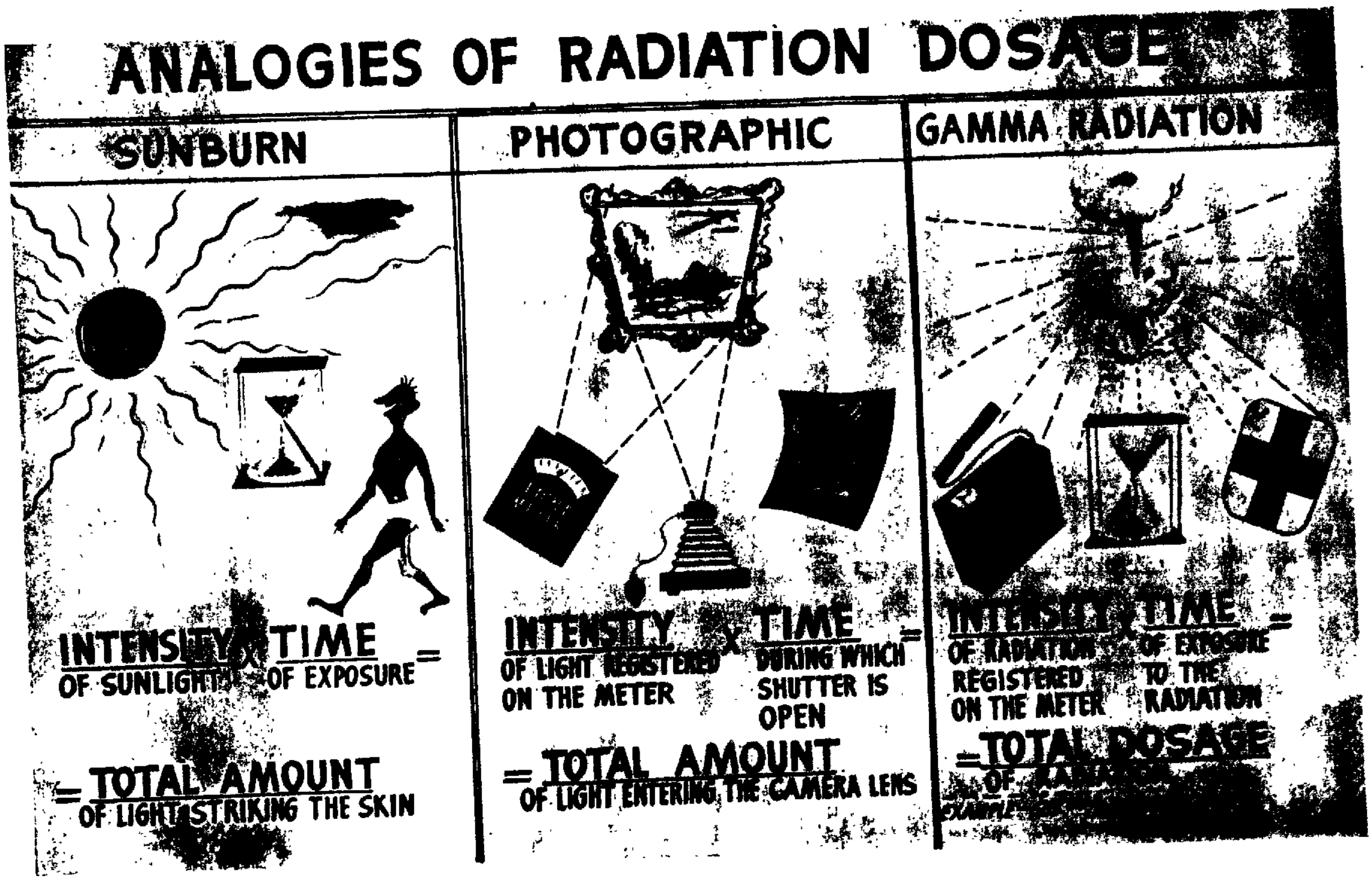

ANALOGIES OF RADIATION DOSAGE
SUNBURN
INTENSITY OF SUNLIGHT x TIME OF EXPOSURE =
= TOTAL AMOUNT OF LIGHT STRIKING THE SKIN
PHOTOGRAPHIC
INTENSITY OF LIGHT REGISTERED ON THE METER x TIME DURING WHICH SHUTTER IS OPEN =
= TOTAL AMOUNT OF LIGHT ENTERING THE CAMERA LENS
GAMMA RADIATION
INTENSITY OF RADIATION REGISTERED ON THE METER x TIME OF EXPOSURE TO THE RADIATION =
= TOTAL DOSAGE

Figure 27.

tensity of radiation in roentgens per hour. Expressed with commonly used units—

$$D(\textit{milliroentgen}) = I(\mathrm{mr/hr}) \times t(\mathrm{hr})$$

Two devices widely used for determining radiological dosage are the film badge and the pocket dosimeter.

The film badge is a simple device consisting of a photographic film especially sensitive to the type and intensity of radiation to be measured. The film is enclosed in several layers of paper and in some applications the badge is partly covered by a sheet of metal, such as lead. The paper effectively stops light and all alpha particles. The sheet of lead stops the beta particles. The lead shield not only passes gamma radiation but greatly intensifies the blackening of the film from this type of radiation because of scattering effects of the lead. This makes it possible to use a single badge to determine total exposure due to both beta and gamma radiation.

In use, the film is held in a small holder (fig. 22) suitable for clipping to clothing. Developing the film after exposure to radiation shows a blackening effect similar to that produced by light on an ordinary photographic plate. The intensity of film blackening indicates the amount of radiation received. The densitometer (fig. 28) is used to measure the amount of blackening.

Before the radiological exposure or dosage can be determined from the developed film it is first necessary to construct a calibration curve. Such a curve for Eastman type K dental X-ray film is shown in figure 29. This curve translates the blackening of film due to radiation as measured on a densitometer into radiological exposure in roentgens. The densitometer thus is a direct-reading dosimeter when used with the exposed film badge.

Film badges are cheap and give a permanent record of the exposure of individuals. However, due to the photographic processes involved and the numerous handling operations, accuracy is not greater than 10 to 20 percent. The basic film badge may be modified in a number of ways so that it may respond to one or more types and amounts of radiation.

Figure 28. Densitometers.

One disadvantage of the film badge is that exposure is not known until after the film is developed. In some cases this may be too late. To obtain the radiological dosage of an individual at any time, pocket dosimeters are used. There are two general types of pocket dosimeters, the nonself-reading type and the self-reading type.

The nonself-reading type actually is an electrostatic condenser. Such a condenser consists of two conducting surfaces separated by an insulator. A definite electric charge is placed on the dosimeter by an auxiliary device known as a minometer (fig. 21). Ionization produced within the dosimeter by some external ionizing radiation neutralizes this electrostatic charge. The loss of charge is measured by a minometer calibrated to read total dosage in roentgens.

The self-reading type of dosimeter operates like a gold-leaf electroscope with one leaf fixed and the other movable. The movable leaf moves across the built-in transparent scale calibrated in roentgens of dosage. In use, the dosimeter is given an electrical charge by means of a charging unit (fig. 21). The total dosage can be read at any time, without the use of an auxiliary instrument, by looking through one end of the dosimeter at a light source.

To record neutron radiation, a specially constructed pocket dosimeter is used. A neutron dosimeter is similar in all respects to the nonself-reading type except that the walls of the chamber are lined usually with boron. A neutron pocket dosimeter and its auxiliary charging and reading unit are shown in figure 21.

A comprehensive personnel radiological monitoring program would use both film badges and pocket dosimeters. Each individual wears a film badge and one or more dosimeters. The film badge gives a permanent record of the weekly dosage while pocket dosimeters give the daily dosage. The self-reading type gives the dosage immediately but is more expensive and more fragile than the nonself-reading type. Although present film badges and pocket dosimeters are

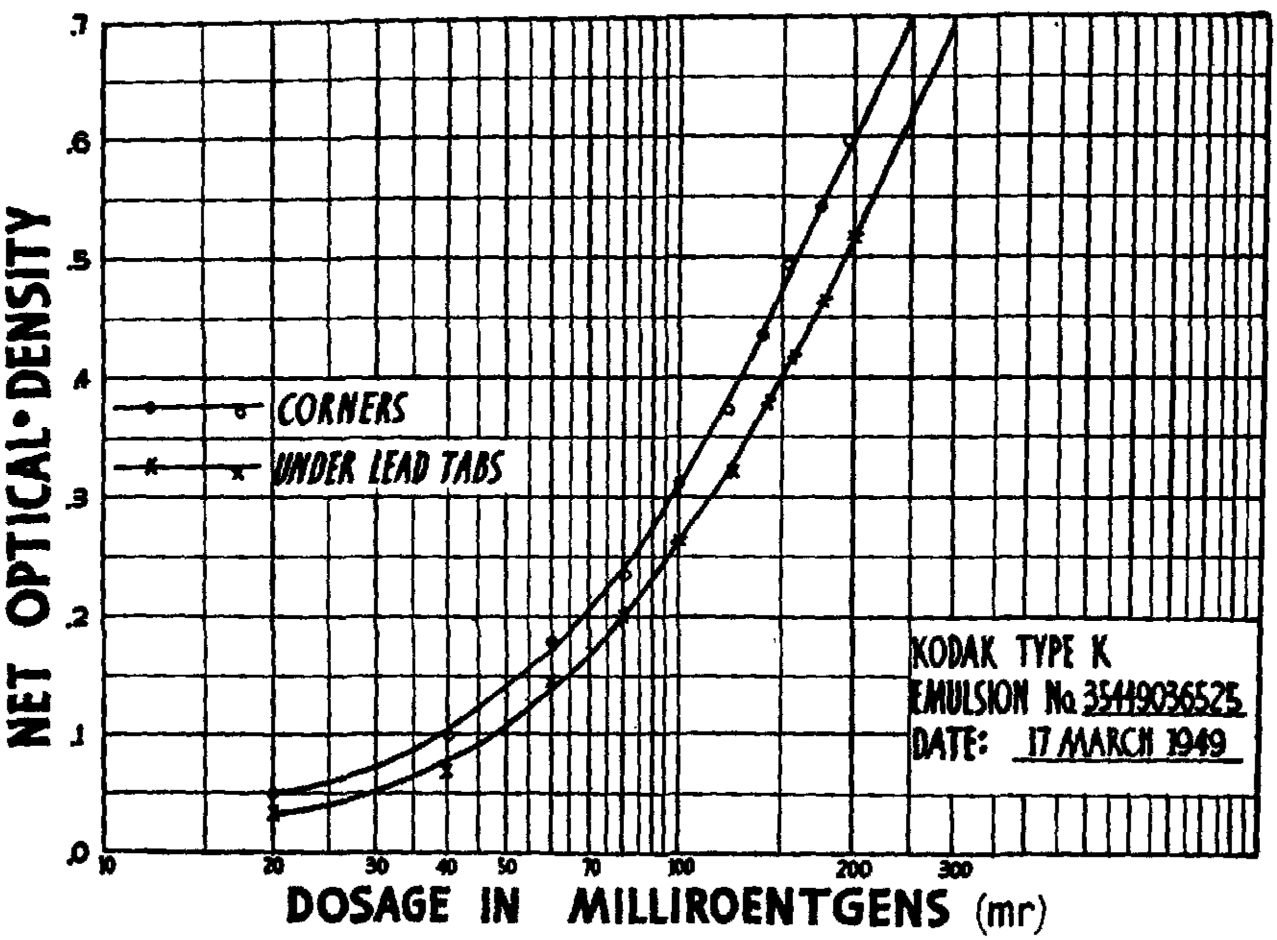


Figure 29. Calibration curve for kodak industrial X-ray film type K.

quite satisfactory for monitoring personnel in industrial and research installations, they are not entirely suitable for military needs. Considerable development work is being done to produce suitable dosage devices to meet the particular needs of the Armed Forces.

Section III. TIME-INTENSITY PROCEDURE TO CONTROL EXPOSURE TO EXTERNAL GAMMA AND BETA RADIATION

The procedure for control of exposure to external gamma and beta radiation after an atomic burst is based primarily upon determining first, the various intensities of radiation within a radioactive area and, then, the time personel may remain in any particular part of the area in which they must work or remain.

Any contaminated area must be indicated clearly by signs or posters as soon as possible. The signs must indicate—that radioactivity is present, the intensity and time measured, and the length of time that personnel may remain without exceeding the daily tolerance dose set by the command. Naturally, the signs will have to be changed from time to time because of the change in intensity resulting from radioactive decay. Then, they must be changed in accordance with the latest intensity readings. This work must be done under the supervision of the radiological defense officer.

Certain areas may be ordered "off limits" and clearly indicated and guarded as such. On the other hand, it will be required that many areas be occupied for military needs or civil defense. A few highly radioactive areas may have to be entered for rescue or important repair work. For example, a railroad station ordinarily cannot be neglected after damage.

A practical method of determining the time which personnel may remain in a radioactive area has been explained in the paragraph on radiological dosage vs. intensity of radiation. The calculation is sufficient for short periods of time, but if the calculation is made for a period of one-half day or more, the error will be much too great. The reason for this is that the radioactivity is changing all the time and the intensity is considerably less after a few hours or a day. It is to be noted though, that the time obtained from the formula given is always a little less (or much less for longer periods of time) than the true figure. Further calculation can be made to obtain an accurate figure for the permissible time. However, not everyone is expected to do the more complicated problems.

Actual calculations of this nature and interpretations of chart readings as given in the last chapter should be done by competent authority, or by someone under his supervision, at a control center from which the information can be disseminated expeditiously. Too many personnel attempting to do their own calculations would only cause confusion and create error and misconception throughout the command. One control center with adequately trained personnel is sufficient for one blast area. Training in this type of work is now given in the six-week radiological defense schools. It is expected that the radiological defense officers will give similar training to other personnel of their respective installations to assure that adequate qualified personnel will be available as assistants for possible emergencies.

Where there is only an external hazard, control to prevent overexposure will be a rather simple matter, but where contamination of radioactive dust particles is present, there is a more serious problem. Study of explosion phenomena in chapter III is suggested here.

Section IV. TECHNIQUES FOR PROTECTION AGAINST INGESTION OF INTERNAL HAZARDS

At any time that radioactive dust is present, the danger of internal hazards is serious. Small dust particles containing the radioactive atoms are easily ingested by eating, drinking, or smoking. Thus, personnel should not be allowed to eat drink, or smoke until after they have been proved to be free of contamination by being monitored outside the area.

Protective clothing and gas masks always should be worn while in danger of radioactive dust. The clothing does not shield against the radiation itself, but it does prevent body contact with the dust particles which will continue to emit radiation. Any sort of canvas or heavy fabric wrapper worn over the shoes is helpful in minimizing contamination of the shoe. Standard Chemical Corps' protective clothing with the gas mask is useful, but improvisations may be made of any other disposable material. Long underwear should be worn beneath the outer garment.

For high contamination the impermeable clothing is used. Air is almost completely shut out, preventing body contact with dust. The hood covers the head, neck, and top of shoulders. The bottoms of the trouser legs and sleeve ends are drawn snug with straps. The suit offers practically 100 per cent protection against contaminated air, but it is exceedingly uncomfortable if worn without a cloth cover.

The cover is very important. It is worn wet over the suit. The evaporation of the water keeps the wearer cool, allowing him to work for much longer periods. The suit with wet cover may be worn for one-half day or more. Without the wet cover the suit can be worn only for one-half to one hour. As the cover dries, more water is added to keep it damp or moderately wet as required by the wearer. Two people can easily work together with a supply of water to wet or dampen each other. Caution should be taken to keep the water free of contamination, although slight contamination of the water would not present a serious hazard because the suit would prevent body contact with the dust. Contaminated water would at least add to the problem of decontaminating the clothing and should be avoided unless absolutely necessary to the wearer.

Items to be worn in high contamination are—

(1) Gas mask
(2) Impermeable suit (including hood).
(3) Impermeable boots or canvas wrappers to cover shoes.
(4) Impermeable gloves.

Where it has been determined by competent authority, or authorized personnel under his supervision, that contamination is not high enough to warrant use of the impermeable suit, the permeable type of protective clothing may be worn. Gas masks must be worn. Here, again, the long underwear will give added protection against body contact with contamination.

It should be borne in mind that the permeable clothing should be worn when permissible. It is more comfortable and permits more freedom of body action. The efficiency of the individual can be needlessly reduced through the over use of the impermeable suit. In fact, the need for the impermeable suit would be rare.

Items of permeable clothing and equipment are—

(1) Gas mask.
(2) Hood to cover head and neck.
(3) Canvas leggings.
(4) Canvas bootees or disposable wrappers, if available, to cover shoes and ankles.
(5) Fatigues.
(6) Gloves.

Figure 30 shows the impermeable suit. Figure 31 shows the cover worn over the impermeable suit.

All persons leaving a contaminated area should report immediately to the most convenient personnel decontaminating station where they will be decontaminated and receive fresh clothing.

Figure 32 shows the dress for normal field survey while figure 33 shows normal dress when air contamination is present.

Figure 30. Impermeable suit.

Section V. DECONTAMINATION

The subject of decontamination is still under serious study, and thus far only slow progress has been made. Decontamination actually constitutes such a problem that it is wisest to avoid contamination, if possible. There is no practical way to destroy radioactivity. Since radioactive decay, a nuclear process, is entirely unaffected by chemical reaction, decontaminating solutions such as are used in neutralizing mustard gas contamination are of little value in this new situation. Radiological decontamination has as its objective the freeing of an area from persistent radioactive agents. This involves the actual removal of induced radioactive isotopes, fission products, and/or unfissioned parts of the fissionable material of the bomb itself.

Figure 31. Impermeable suit with fabric cover.

Figure 32. Dress for normal field survey.

Currently accepted practices of decontamination include the following procedures:

The immediate reduction to a minimum of that contamination of personnel and vital installations which has not been avoided. This may include—

- Complete bathing, monitoring, reclothing, administering medical treatment where required, and evacuation of affected personnel.
- Washing and scrubbing exposed surfaces to free them of loose contaminating particles.
- Temporarily covering short-range emitters (alpha or beta) with a coating, such as paint,

which will provide at least a partial shield against the emissions.

Subsequent thorough decontamination of important matériel may include—

Repeated scrubbings.

Removal of closely adhering particles by chemicals such as citric or hydrochloric (muriatic) acids, which render the particles more soluble.

Removal of the surface to which the particles cling by the use of paint-removing solutions, scraping, or possibly wet sandblasting.

The value of such operations should always be weighed against the possibility of temporary or complete abandoment of the area or installation, or of prescribing certain maximum periods of working time for personnel absolutely required to enter dangerous areas.

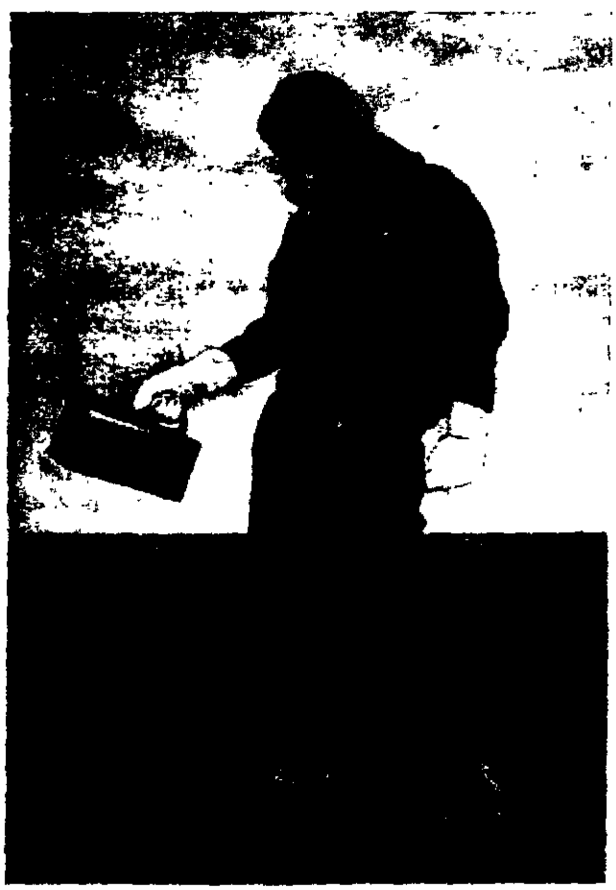


Figure 33. Normal dress for air contamination.

The prevention of the spread of contamination may be accomplished by—

Preventing access to particularly "hot areas" by proper isolation, which will include plainly marking-off dangerous areas.

Using great care in disposing of grossly contaminated objects and the waste water and waste materials used in removing contaminating particles.

Carrying out a carefully prescribed ventilation doctrine (filtration) in the case of ships or air-conditioned shelters.

Improvising a change station, or decontamination center for the thorough decontamination of personnel and their clothing and equipment before returning to a clean or uncontaminated area after exposure to possible contamination. Contaminated personnel must wash themselves (paying particular attention to hair, feet, hands, and finger nails), possibly many times, until, upon being monitored, their bodies are found to be at a safe level (at Bikini—Twice background count). Clothing must be changed and the contaminated clothing laundered, or if repeated laundering fails to decontaminate it, it must be destroyed.

Considerable original thinking and experimentation still is needed in order to give practical answers as to what corrective measures can be applied in future situations involving radiological hazards. Current and future development of radiation detection equipment will probably result in more practical and more effective instruments than those now available to assist the monitor in the conduct of a radiological survey. Surfaces of such smoothness and low porosity that they can be easily decontaminated will possibly be developed for structures and equipment, or perhaps surface finishes which can be removed, when necessary, carrying the radioactive particles with them, may prove one answer to the problem of radiological decontamination. These problems should be seriously considered. Research on these matters is being continued both in the laboratories of the Atomic Energy Commission and in such installations as the Naval Radiological Defense Laboratory, San Francisco Naval Shipyard, San Francisco, Calif. It is expected that these studies will shed light on the best methods and materials to be used in decontaminating radioactive surfaces.

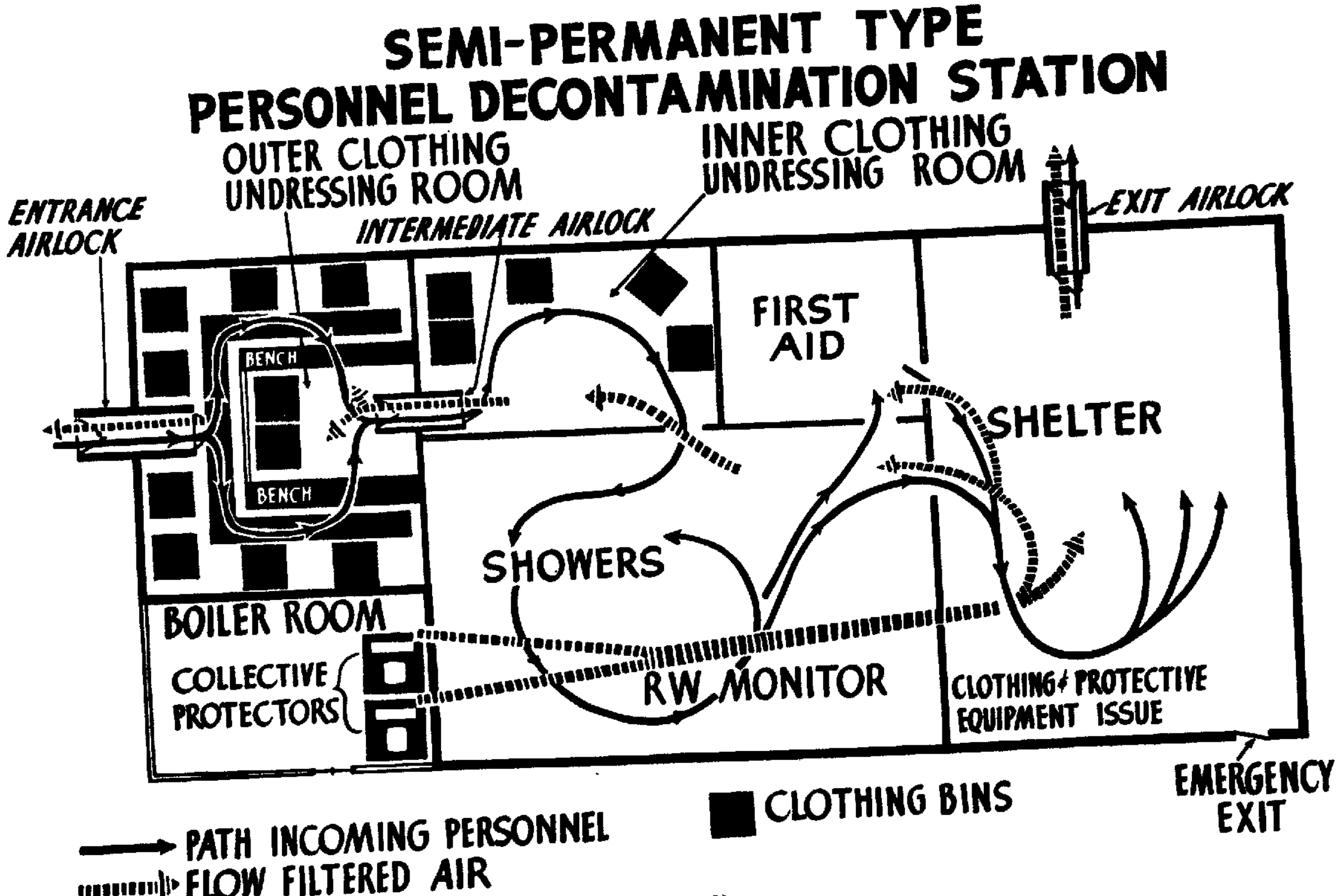

SEMI-PERMANENT TYPE
PERSONNEL DECONTAMINATION STATION
OUTER CLOTHING
UNDRESSING ROOM
INNER CLOTHING
UNDRESSING ROOM
ENTRANCE
AIRLOCK
INTERMEDIATE AIRLOCK
EXIT AIRLOCK
BENCH
BENCH
FIRST
AID
SHELTER
SHOWERS
BOILER ROOM
COLLECTIVE
PROTECTORS
RW MONITOR
CLOTHING & PROTECTIVE
EQUIPMENT ISSUE
EMERGENCY
EXIT
CLOTHING BINS
PATH INCOMING PERSONNEL
FLOW FILTERED AIR

Figure 34.

Section VI. PERSONNEL DECONTAMINATING CENTER

A station for decontaminating personnel contaminated with radioactive materials can be constructed similiar to the present chemical decontaminating station. Actually, one station might serve both purposes. Considerable experimental work has been done on designing a standard station, and further information is expected to be forthcoming. However, the general plan of present stations will not be changed. The basic principles are illustrated in figure 34.

Any station must consist of at least three fundamental elements—an undressing room; a decontaminating, or "clean-up" room; and a dressing room. In the undressing room, boxes or bins are placed in convenient rows for collecting contaminated clothing. A bin is needed for each item of clothing—a bin for gloves, a bin for shoes, a bin for leggings, etc. Separating the clothing item by item aids in decontaminating them later. Benches must be at hand to permit ease of undressing. Since the first room may contain considerable contamination, an air lock, therefore is constructed in the passage to the decontaminating room.

A second, or auxiliary, undressing room between the first room and the shower room is helpful. Here the inner and less contaminated items such as underwear, or possibly sweaters or jackets worn beneath the protective suit in cold weather, may be deposited. Then, the clothing may be placed in decreasing order of contamination, thus minimizing the problem of decontaminating it.

Good showers are mandatory. Radiological decontamination is exceedingly difficult because minute dust particles lodge in the pores of the skin and on the hairy parts of the body, often making several scrubbings necessary. Heaters, or a furnace for heating water, are greatly needed for such difficult cleaning work, but under no circumstances should a decontaminating procedure be stopped or excluded because of lack of hot water. If hot water is not immediately available when needed, the decontamination should be begun immediately, and then all effort possible made to obtain hot water.

A first aid room is best situated near the shower room, preferably near the passageway to the dressing room. There is no need to place the first aid room before the shower room because a shower is usually taken first in radiological first aid. The Medical Corps will have its own means of decontaminating and caring for serious casualties unable to shower themselves.

A small space for monitors is needed at the exit of the shower room. Care must be taken to keep benches or storage bins far enough away from the door to allow ample room for at least two monitors to examine two people freely. Approximately 5x5 feet of space is sufficient.

The dressing room should be constructed of hard, smooth surface material in order that it may be cleaned thoroughly. Storage bins for fresh clothing should be placed neatly near the wall to safe space for dressing. Too little space to dress may cause delay and hold up decontaminating procedures. Furthermore, neatness in the dressing room promotes adequate cleaning.

Cleanliness is paramount in a decontaminating station.

The station illustrated in figure 34 has been used experimentally. It is estimated that this station is adequate to handle approximately twenty persons every twenty minutes if they are properly trained. Naturally untrained personnel will require instruction throughout the cleaning procedure and will consume much more time. This must be taken into consideration when planning the station.

In planning any decontamination station, one should consider the following:

(1) An estimate of the number of personnel expected to be served per hour.

(2) A location as convenient as possible to the personnel to be served.

(3) A location not likely to become contaminated.

(4) Availability of water

(5) Route of approach.

(6) Route of departure.

Section VII. CONTROL PROCEDURES FOR ISSUANCE OF EQUIPMENT AND PROTECTIVE INSTRUMENTATION

As previously pointed out, much of the currently available radiac equipment does not meet military requirements. The Armed Forces through their various research, engineering, and development divisions are engaged in an intensive program which will result in supplying radiac equipment for military needs in the very near future. As these pieces of equipment emerge from the rigid testing schedules and the supply becomes adequate, T/O&E's will be promulgated for individual military commands to follow.

In the meantime, each military unit will use such commercial equipment as is currently available. Where no standardized procedures have been established local authorities will find it advantageous to institute some routine procedure in order to prolong the life of the instruments and to control the accountability of the equipment. To assist local commands in setting up these control procedures until such time as official T/O&E's are issued, the various aspects of radiac equipment control are discussed below. The factors presented also are suitable for Civil Defense authorities in coordination with local army activities in setting up radiac control procedures.

The problems involved in setting up an adequate control for the issuance of the many radiac instruments and protective devices involved in a very large organization and extensive operations are numerous. It is not possible, in this short space, to point out or even to anticipate all the problems that are bound to arise and that have to be met. It is, therefore, the purpose of this section merely to outline the various steps involved in such a program and to add, wherever possible, additional statements of caution. It will be the duty of the radiological defense officer for the activity to initiate, set up, and direct the procedure involved. Much of the success of a radiological defense mission will depend on how well this particular job is accomplished, for without instruments, any radiological defense operation will be much like a blind man leading the blind. Consequently, much thinking and great effort must be brought to bear on the problems of setting up proper, adequate, and effective control procedures.

Basically, it must be emphasized that the equipment and instrumentation required must be available and in operating condition. All effort should be pointed in the direction of performing this basic requirement.

Effective control procedures must involve the following steps:

1. Requisitioning the necessary equipment and in the right quantity.
2. Receiving the equipment when it arrives.
3. Checking the equipment to see that it is what is needed, the proper amount, and that it is in good shape.
4. The proper storage of the equipment.
5. The proper lower echelon calibration and maintenance of the instruments.
6. Proper amount of spare parts, batteries, tubes, etc.
7. Issuance control to the operating personnel.

Step 1—Requisitioning the equipment. A search should be made of the local military activity to determine the official directives on the procurement of equipment.

Step 2—Receiving, and Step 3—Check the equipment when it arrives. This particular phase of the problem is largely in the hands of the local radiological defense officer and his assistant. Generally, army equipment is shipped with instruction manuals. These books should be carefully filed in order that they will be available when needed. They should be consulted frequently for detailed information on the particular instrument covered. It is very important upon receiving equipment not previously stored to see that replacement parts, batteries, etc., are available at the same time, so that the new instruments may be kept in proper operating condition.

Step 4—Storage. As more and more of the instruments issued meet military specifications, it can be expected that the storage problem will decrease in importance. Instruments will be built to withstand wide ranges of local conditions, such as temperature and humidity. Commercially available instruments, on the other hand, will require more care. At the present time, most of them need to receive attention regarding moisture and temperature protection. Some attention also must be given to stock control, so that as instruments and supplies are used, adequate replacements will be ordered in sufficient time to be available when needed.

Step 5—Lower echelon calibration and maintenance. Most radiological equipment is similar to other electronic equipment. For first echelon maintenance the primary emphasis will be on the replacement of the batteries and possibly a few minor items, such as tubes. However, for major repairs, it is anticipated that properly trained personnel will be available. It is important to know where these trained personnel are located at any particular military installation so that, in an emergency, instruments may be dispatched to these agencies with a minimum disruption of service. Here, again, the technical manuals furnished by the Army with the equipment provide the best and most reliable source of information.

Step 6—Spare parts control. This feature raises the problem of having sufficient spare parts to maintain the equipment at first echelon maintenance stage. An important responsibility of the using activity is the proper calibration and maintenance of all instruments. If large numbers of instruments are involved, it is best to set up a standard calibrating procedure which can be employed easily at a moment's notice. If film badge service is to be included, then a standard operating procedure for the calibration and development of film badges should be initiated.

Step 7—The control procedure for the actual issuance of the equipment to operating personnel. The purpose of establishing the control procedure is to maintain an accountability system. This is made necessary by the large number of items and the frequency of issuance. In large installations such a procedure will certainly necessitate the setting up of an issuance room where operating personnel will turn in their instruments daily and have their equipment checked. In addition to a physical count of the instruments as they are turned in, the condition of the instruments must be checked to determine their condition for reissuance. Under an actual emergency condition this might require the maintenance personnel to function after duty hours and throughout the night, so that all equipment will be in top shape for issuance the following morning. If the large film badge service or other dosage recording devices are to be issued and adequately processed, a great number of personnel will be involved in the large amount of record keeping which will be necessary.

Many agencies of the Department of the Army are involved in the instrumentation for radiological warfare. To the Signal Corps has been given the cognizance for the development and maintenance procedure for the Army of all electronic radiological instrumentation. Film badge service and the concomitant procedures involved are under the cognizance of The Surgeon General of the Army. The development of the various types of chemical dosage indicators to meet the military requirement of the Army Field Forces is under the cognizance of the Chemical Corps of the Army. These agencies will issue specific directives from time to time covering the various instruments, devices, and indicators under their cognizance. It is important that every radiological defense officer keep himself thoroughly acquainted with these directives.

A helpful point to keep in mind is that all operating procedures should be held at the absolute minimum so that everyone involved may quickly and easily learn to follow them; to keep these procedures as straightforward and as simple as is consistent with the problem involved. For first echelon calibration and checking of instruments, it might be sufficient simply to check several instruments. By comparing several instruments, it is easily determined which is the defective one. Bear in mind that under emergency conditions the tolerant dosage will be considerably higher than under peacetime labortory operating conditions. Hence, it is not necessary that instruments be calibrated with laboratory precision. They should give a reading that is of the right magnitude and within a reasonable amount. Good protection policy would include a certain safety factor. Hence, the extra effort and care in trying to maintain radiological survey instruments at laboratory accuracy is cumbersome and unnecessary.

CHAPTER 7

COMMAND ASPECTS IN ATOMIC WARFARE

Section I. GENERAL

This chapter covers certain command problems arising from the radiation hazard and presents them from the commander's point of view.

An enemy undoubtedly will mark certain of our vital areas as key targets for atomic attack. These areas, although marked for atomic catastrophe, will not necessarily be doomed. It is these areas which present problems of direct concern to radiological advisers.

In an air burst of an atomic weapon, the predominant effects are blast, radiant heat, instant radiation, and secondary fires; the secondary effect is radioactive contamination which is relatively small. In the downwind direction, areas may be found slightly contaminated by radioactive material falling out as it is carried along by the wind. This occurrence is frequently referred to as "fall out". The degree of contamination will not be a primary hazard. (See appendix V.)

In an underwater burst, the predominant effects are radioactive fall-out contamination and water-propagated blast and they constitute an extremely serious threat. The water absorbs, shields, or minimizes the effect of instant radiation, air blast, radiant heat, and secondary fires. In order to obtain an extremely large volume of highly radioactive material on a target, the effect of blast and heat is reduced.

The probable results of a subsurface burst are purely speculative, but some broad conclusions can be drawn by analogy with the underwater burst. Predominant effects would be radioactive contamination (from the fall-out of soil-trapped fission products and from neutron-induced reactions in the elements of the soil) and, to a less extent, air and ground shock wave. Secondary effects would be instant radiation, radiant heat, and fires. Since the dissipation of the heat generated in a subsurface burst could be expected to be slower than in an underwater burst, the cloud would rise higher and would be influenced to a greater extent by wind conditions.

Section II. RADIOLOGICAL DEFENSE

Radiological defense is defined as the protective measures taken to minimize personnel and matérial damage from radioactivity, and is interpreted to include measures such as—

a. Training, organization, and distribution of personnel.

b. Development, provision, and maintenance of fixed and portable structures and equipment.

c. Development of techniques and procedures including use of detecting equipment, protection or removal of exposed personnel, and decontamination of personnel, equipment, structures, or terrain.

ARMY PLAN FOR RADIOLOGICAL DEFENSE

The purpose of this plan is to establish a radiological defense organization within the Department of the Army (See app. VII.) This plan provides for—

a. The protection of Army personnel, units, and establishments against the effects of radioactivity, and the maintenance of the operational efficiency of the army in the presence of radiological hazards.

b. The support of civil radiological defense control and relief measures in accordance with the Army's established policies for providing assistance to civil authorities in connection with disaster relief operations.

Command responsibilities. The radiological defense training of the unit and of the individuals in the unit, and the protection of the unit against radiological hazards, are basic responsibilities of command.

Responsibilities of Department of the Army agencies. *a.* In the implementation of the Army radiological defense program, responsibility for operational control measures, training procedures, research and development, and logistical support will be charged, wherever possible, to those Department of the Army agencies now performing similar functions within their established fields of responsibility.

b. Certain fields of responsibility with respect to radiological defense organizational and training functions are enumerated in chapter 8.

c. Fields of responsibility pertaining to research and development activities in the field of radiological defense, and to the logistical support of the Army radiological defense program, will be determined and promulgated by the Assistant Chief of Staff, G-4, Logistics, General Staff, United States Army.

Some of the specific aspects which might be expected to come up for consideration in most commands are—

Setting up roster indicating radiologically exposed personnel and keeping permanent records of radiation exposure.

Manner of reporting areas of radiation contamination for intelligence purposes.

Procedure of reporting by subordinate units of new or unexpected means of employment of atomic weapons by an enemy.

Countersabotage and countersubversive plan.

Dissemination of information concerning the enemy's capability of employing atomic weapons, including possible targets, means of employment, and time of attack.

Unit training of unit gas officer and noncommissioned officers within unit schools.

Requirement of the command for specialized (such as monitor, decontamination, and photodosimetry) training, all training to be at specialist schools.

Training within the command, such as general indoctrination, unit training, combined training, and exercises.

Unit standard operating procedure to minimize radiological hazard.

The alert and alarm plan and active defense plan.

Class IV items necessary to cope with radiological problems.

Section III. SPECIAL STAFF DUTIES

A number of special staff officers will be affected by the new requirements of radiological defense in accordance with specified policy or the wishes of the commander.

1. The staff chemical officer is a member of the special staff. His duties as specified in FM 101-5 are given in detail here.

a. Exercises operational control of all chemical units not assigned or attached to subordinate commands.

b. Advises the commander and staff on chemical matters including the coordination of the use of biological agents, incendiaries, and smoke by the various arms.

c. Determines requirements for, procures, stores, distributes, issues, and documents chemical supplies.

d. Makes recommendations for procurement and employment of chemical troops and their allotment to subordinate units.

e. Prepares and supervises training programs of chemical units under his operational control, and exercises technical supervision over chemical training throughout the command.

f. Plans and supervises chemical operations, including the following:

(1) Estimation of the requirements of all chemical-filled munitions to all units of the command.

(2) Employment of mechanical smoke generators and smoke pots for extensive area screens.

(3) Chemical defense, to include gas-proofing of enclosures and installation of collective protective equipment.

(4) Decontamination.

(5) Employment of toxic chemicals in tactical, operations.

(6) Radiological defense surveys and the determination of radiological hazards.

(7) Biological warfare survey and the determination of biological hazards.

(8) Operation of maintenance and repair facilities and processing plants, including the field filling of chemical munitions, that may be established within the command.

(9) Examination and processing oi captured chemical supplies.

(10) Collection, evaluation, and dissemination, in coordination with G-2, of information concerning enemy chemical warfare activities.

2. The *medical officer* would be interested primarily in the health and physical condition of the command. He may provide for the development of film badges and maintain exposure records on members of the command. He advises the commander when radiation exposures constitute a damaging physical hazard. In accordance with directives from higher authority, he establishes the exposure limits for the command. He is responsible for the tremendous task of setting up a plan for the evacuation and treatment of casualties and for the execution of this plan after an attack. He also may be called upon to assist in handling civilian casualties, particularly in zone of interior attacks. It is imperative that medical personnel operate in the disaster area as soon as possible; in the event of an air burst, they will most likely be on the job before a rapid survey can be completed. For the sake of the injured, and for the sake of the morale of those uninjured, immediate and efficient handling of casualties resulting from nuclear weapon attack is mandatory.

3. The engineer officer would supervise the construction of installations required for radiological defense. The engineer consults the radiological defense officer concerning the optimum protection to be gained through special types of construction and the location of new shelters, personnel decontamination stations, and special command posts.

4. The *signal officer* would be responsible for supervising storage and repair of instruments at the command level. He might also receive and issue, in bulk, film badges and photodosimetry equipment. He also may be required to provide photographic dosimetry facilities.

5. The many other special staff officers would have individual problems which would be worked out by coordination with the radiological defense officer or by direct instruction of the commander.

After all staff members' recommendations have been submitted and consolidated, the operations officer translates them into an SOP which forms the basis of radiological defense within that command. This plan gradually undergoes changes as it is repeatedly put to test or as the command receives new instructions, until it is eventually sound and practical.

Section IV. SPECIAL PROBLEMS

Much profitable information and guidance can be extracted from experiences in operations involving large-area radiation contamination. A command problem which was potentially very serious arose at the Baker test of Operation Crossroads. The Baker test explosion was different from those at Hiroshima and Nagasaki; in Baker test, there was an added hazard from the radioactive materials trapped in the water and rained on the target vessels. Men walked through radioactive material scattered over the decks of the ships, tracked it around, and got it on their clothing and exposed parts of their bodies. Since they could not see, feel, or smell it, they did not respect it, but they could eat it and they could inhale it.

At Bikini, operations could be interrupted any time plans, group training, or operational techniques became inadequate to assure complete protection to personnel. During combat, however, plans and training must be such that an organization can continue to function.

After the Bikini operation was discontinued, the target vessels were towed to Kwajalein and anchored in the lagoon for long-term storage. The need for further work on the vessels was apparent, and it also was evident that a complete quarantine of the ships would not remain practical. The ships contained large amounts of high explosives, including some experimental ammunition and some obtained from foreign navies. Removal of this ammunition was necessary, and the longer operations were deferred, the more dangerous the work would become.

Frequent briefings of the men were held by the officers to impress the need for caution, not only against the dangers from radioactivity but also against the dangers of handling explosive materials and working in poorly ventilated spaces. The protective restrictions which were established were more than those used at Bikini. Every tendency to relax precautions had to be countered by a psychological campaign on the part of the officers to insure compliance. This is typical of what may be expected in the future. If the nature of the danger is not directly observable, the control of the troops will present a complex problem. There is a vast difference between impressing a man with the fear of observable physicial injury and impressing him with respect for invisible radioactivity. If fear of radioactivity is taught, the efficiency of atomic weapons will be increased. If proper respect is not instilled, the toll of lives will be increased.

It seems that the command difficulties to be encountered and the lessons to be learned in atomic warfare will include a repetition of some of the difficult experiences at Kwajalein. There will be others that are more complex.

The value of any objective should be weighed against the cost of achieving it. The costs of achieving radiological objectives are not readily observable. When a man has been subjected to some cumulative absorption, which will be referred to as military tolerance, his usefulness for radiological defense (or attack) is impaired. Further exposure will increase the liability of his becoming a casualty. When a commander has held his troops in an area of high radioactivity until he can observe the physical effects upon them, he has held them too long.

The commander of the future must understand the nonperceptible hazards of atomic warfare and know how to evaluate them accurately. He also must know how to weigh the normal, calculated risks against the value of his military objective. He must understand the nature of radioactivity and the slowness with which it acts and makes itself evident. He must be willing to accept the advice of a technical staff on such matters just as certainly as, under other circumstances, he would accept the information of troop losses. He cannot shift to technical personnel the responsibility for failing to drive on to his military objectives, but he must give proper weight to their advice. Military command remains in his hands and cannot be usurped by the advisor or the radiological monitors, but the commander cannot act efficiently if he ignores the advice of such technical personnel, who in such instances would actually give far more advice. They would tell the commander the absolute facts, which he could not immediately see (and therefore might ignore) but which he could not ignore later when the toll was reported from the hospitals; facts which he could not ignore when his reserve troops would be demoralized and beaten without ever having faced an enemy.

During Operations Sandstone (at Eniwetok) there was considerable evidence that the lessons of Bikini were profitably used and contributed to a very efficient, adequate, and commendable radiological defense operation. From Operation Sandstone have come additional valuable lessons pertaining to radiation, lessons that will improve and perfect the over-all concept of radiological defense.

The introduction of new weapons of a nonperceptible insidious character in warfare does not require a revamping of our organization in order to cope with it. It is quite evident, however, that it will demand wisdom, tact, and ingenuity on the part of the staff officer concerned to properly impress his commander. A proven, easily demonstrated weapon can be quickly countered by the optimum defense attainable. For the defense against a weapon whose effects are either shrouded in secrecy or not easily observed, however, implicit faith in the staff officer's technical capabilities will be necessary. Such relationship between commander and staff adviser will be the first step required in orderly movement toward the best solution.

Command problems may arise as a direct result of several factors. Lack of prior planning, for instance, will require quick decisions and improvised plans, some of which may easily prove to be disastrous. Lack of qualified and trained personnel will cause serious delays. Lack of equipment of rigorous and proved design can cause limitations in time of need. The absence of a well-trained and well-organized radiological defense team can impose unnecessary time delays. Command problems directly attributable to these factors can be reduced. Other command problems arising out of unexpected employment of atomic weapons with regard to method, place, or timing can be minimized by thorough intelligence and counterintelligence. In the final analysis, adequate radiological defense depends upon—

a. A competent technical staff.
b. A complete and practical unit plan.
c. A trained radiological defense organization.
d. Adequate equipment, supplies, and facilities.
e. Timely intelligence.

As a practical example of the kind of thinking required by the commanding officer and his staff in anticipating and planning for radiological defense and which at the same time incorporates consideration of many of the principles discussed above, the speech prepared by Captain Frank I. Winant, Jr., USN, Chief, Radiological Defense Division, Armed Forces Special Weapons Project, is presented here in its entirety.

Prudence dictates that we should be prepared for attack whenever a potential enemy is capable of delivering an attack. The United States delivered two atomic bombs with 6 years after the discovery of fission. Therefore, recognizing that others may attempt to match our performance, a readiness date of 1954 or 1955 for atomic attack would not appear early. Unless our defenses are superior to those of Hiroshima and Nagasaki, we can anticipate that an atomic bomb exploded over a major U. S. city will kill or wound on the order of 100,000 people. Of these, 40 per cent will be killed and 40 per cent will be seriously injured. The serious injuries will include burns and radiation sickness and mechanical injuries from collapse of buildings, flying glass, and debris.

We rather expect that an enemy will try to burst his atomic bombs high in the air. When this is done, the instantaneous radiation will assist the blast and heat in taking a toll of lives. As at Hiroshima and Nagasaki, the lingering radiation from the bomb will be negligible. On the other hand, an explosion of the bomb at seriously reduced altitudes, whether by intent or accident, can increase the significance of lingering radiation.

Defensive measures against atomic explosions should lead to the saving of an indeterminate but considerable number of lives. Such defensive measures may be divided into four broad categories:

1. Material measures to prevent instantaneous personel injury.
2. Instructional measures to reduce instantaneous personnel injury.
3. Preventive measures to stop the occurrence of personnel injury after the explosion.
4. Curative measures to increase life expectancy of injured personnel.

Of these, the material measures seem most appealing. In theory, so much can be done. Wide application of such measures, however, appears improbable because of economic considerations. The concept of making every building proof against an atom bomb is perhaps more unsound than the Maginot line theory of defense.

Where the importance of a particular objective demands, the proofing of structures against the atom bomb appears possible. The alternative is defense by dispersal. Insofar as we are bound to an economy characterized by large cities and large industrial units, we are highly vulnerable to atomic-bomb attack. Under such circumstances, an atomic bombing like that at Hiroshima can kill more people than were killed by bombs throughout England in World War II.

Radiological defense consists of protective measures to minimize personnel and material damage caused by radioactivity. Radiological defense does not purport to make war safe. It cannot remove atomic bombings from the category of unspeakable disaster. But if it can reduce death and disorder, expedite recovery of a few thousand persons, and permit removal of critical war materials, the defensive effort of training and equipping limited numbers of radiological defense personnel will pay for itself at any disaster scene.

Let us consider some ways in which radiological defense measures can pay off. We can instruct people with the object of reducing injuries provided they have a warning of the explosion. There might be no warning. But a fraction of a second will help. People can be taught to shield themselves. Thermal shielding is of greatest importance. A handkerchief over the face will help. A shirt, a blanket, a tree, anything between you and the bomb will reduce the flash burns. At certain distances from the blast this shielding may allow treatment for radiation to replace hospitalization for thermal and radiation exposure combined.

Shielding against instantaneous gamma radiation is of comparable importance but is harder to effect. Here again, anything constitutes a shield, but heavier shielding is necessary to give significant protection. Three inches of concrete, although inadequate at close range, might provide a good protective factor at greater distances. In many situations, substantial buildings can provide a degree of radiation shielding. There is, however, the need for an evaluation of the protection provided by various types of buildings to be found in a typical target area as against the hazards of collapse.

We can, with some hope of benefit, teach fundamentals of self help; avoidance of fire, radioactive areas, and overcrowding.

The next defensive category consists of measures to prevent occurrence of personnel injury after the explosion of the atomic bomb. This field is of major significance to the radiological defense personnel. It involves rescue of persons who are in radioactive areas as well as control of those who must be sent to work there. The combating of fire will be of major significance in rescue operations. Many people who could have been rescued will burn to their deaths. Radiological defense operations should assist the general rescue efforts, which will include not only personnel recovery and fire fighting, but also control of panic, logistics, communications, and many other passive defense measures. Radiological defense must not impede the rescue of endangered personnel. It must not delay operations or permit overemphasis of the less significant hazards.

We must consider the controversial matter of lingering radiation such as that found on the Bikini ships. Regardless of indications in the press, the military have not underrated this hazard. From the defensive point of view, lingering radiation is one of the most optimistic features of the atomic bomb. It is the one thing about which we will really have time to do something. It offers a promise of successful countermeasures. Therefore, we have played it up in our service educational programs and in our service research programs. This year we are spending millions of dollars in the national military research and development programs to combate lingering radioactivity as against only thousands of dollars to combat thermal effects. Since we can see the way clear to spend these millions intelligently and profitably, we will not cut back on such effort.

In a catastrophe so vast as that resulting from an atomic bomb, any preparatory effort which can reduce loss of life is justifiable. It is also worthy of a proper evaluation. Considering that lingering radioactivity will be virtually nonexistent in the case of the normal air burst, such an evaluation places it low on the scale of hazards which will confront us. And if we engender in our radiological defense personnel and in our military commanders an unreasoning fear of lingering radioactivity, we shall probably take an unnecessary toll in American lives.

Curative measures will be concerned largely with mass treatment. Therefore, the logistics phases are very important. Provisions must be made for large stocks of blood and for dressings. Hospital space and medical personnel will be at a premium. The sorting of casualties to place those with lesser injuries at first-aid dressing stations and away from the hospitals will be necessary.

The problems raised here are different from the problems of conventional warfare only in point of the magnitude of effort and preparation.

The problems of radiological defense are of common concern throughout the military services. One important phase of our radiological defense training program is to provide the military commander with assistance in solving the unconventional aspects of these problems. The problems of radiological defense may be subdivided into three categories which I shall call:

1. Psychological aspects.
2. Medical aspects.
3. Technical aspects.

The psychological aspects will prove hardest to deal with. For the most part they deal with unreasonable fear.

Reasonable fear can be a useful thing in our lives. It can cause us to dodge an onrushing automobile or to get inside of a tank or battleship or behind a machine gun. But the hazards of lingering radio-activity are the food of unreasoning fear. Such hazards are nonsensory—they cannot be seen or tasted; they cannot be felt or smelled. They can be internal or external, or both. They can be quick-acting or long-delayed. Lingering radioactivity is not mythical; it can range from insignificance in the case of a high air-burst to considerable significance in the case of ground or water-bursts. It could have preponderant importance in the event of disaster in our own atomic installations or in event of an enemy's resort to some form of radioactive warfare. These versatile qualities of lingering radiation make it a powerful psychological tool. Whether or not we can use such propaganda features against an enemy, we are liable to let them work to our own disadvantage.

If psychological weapons are to be forged against us, let an enemy do it. Let's not penalize ourselves. The general thinking in military circles at the present time is that atomic bombs will be used to produce air-bursts. So long as we feel that an enemy will not find it desirable to exploit the radiological features of the weapon, at a sacrifice in other destructive effects, we should not exploit these features for him and add unnecessary complexities to the panic which will probably follow an atomic bombing. We should not enhance the value of an enemy's weapons by making them psychologically more potent. Radiological hazards should be assumed nonexistent in an atomic-bombed area until they are proved to exist. This would mean that the firemen, police, stretcher-bearers, and medical personnel would have immediate and free access to stricken zones. Radiological monitoring must be conducted promptly to confirm the assumption that an area is safe. This places upon the shoulders of the radiological defense organization the problem of being ready and of having personnel promptly at the scene of any atomic bombing in event of a true radiological disaster.

If the air-bursts of Hiroshima and Nagasaki and test Able have established prima facie evidence that high air-bursts leave little lingering radioactivity, certainly test Baker has provided room for doubt in other instances. It is reasonable to assume that an enemy will create some radioactive areas in the United States, even if only from a malfunctioning of bomb fuzes. These areas will constitute major problems in radiological defense. We can and will work in such radioactive areas. Our atomic tests have proved this. But we must work intelligently.

The military commander will have medical advisers to assist him. But how much physical injury will he accept within his own command? Where and how will he "draw the line?" It is my opinion that the wartime military commander in a radioactive area will establish a limitation for personnel exposure which I shall call the "wartime military tolerance" (WMT). This is an arbitrary guide which will limit the time that personnel may be employed in radiological areas. It can be established as an arbitrary percentage of the median sickness dosage as indicated in the following equation:

$$WMT = K \times MSD$$

MSD means "median sickness dose." It is the cumulative dosage which will cause half of the persons exposed to it to become radiological patients. Such persons will have received some physical injury. There will be blood changes involved, and we can say that the men are radiologically ill. MSD has not been defined with finality. It will vary with the rate of exposure. It may run as low as 100 roentgens for very rapid exposures, and higher than 200 roentgens for slow rates of exposure.

The determination of what constitutes median sickness is a matter of medical research and is not a problem of military command. In terms of conventional warfare, MSD might correspond to the probability that a bullet injury would necessitate hospitalization—obviously a medical, not a command problem.

The equation suggests that WMT, the largest amount of radiation to which a military commander can afford to expose his men, is a certain percentage of the median sickness dosage. We want WMT to constitute a suitable limitation which the commander can prescribe throughout his organization. Its value will depend on the proper choice of the control factor, K.

Let's examine the significance of this control factor. We will find that it must be appreciably less than unity, and appreciably greater than zero and that the exact positioning between its upper and lower limitations will be controversial. The upper limitation will be a medical control. If we let K equal unity and allow personnel to work in radiological areas until they have accumulated up to 200 roentgens, then we shall require the hospitalization of 50 percent of our rescue personnel at a time when all hospitals in the area are already hopelessly overloaded with atomic casualties. On the other hand, we shall find that the prompt medical injuries will decrease as the value of K is decreased below unity. For example, if K were established at 50 percent, then we might expect less than 10 percent of our rescue personnel to become radiologically ill. Under wartime circumstances the losses would not be deemed serious. Injuries resulting from a K of less than 50 percent would probably be more on the psychological than the physiological side.

There is another consideration in establishing the upper limitation of K which I will call a "margin of error." When a wartime military tolerance is established, it is meant to be an actual working tolerance to which the local commanders can subject their troops with assurance. Therefore if WMT lies right on the borderline of physical injury, we shall find that those persons who unwittingly exceed the WMT will be endangered. This is not desirable. It is almost impossible to insure that some personnel will not exceed any established limit, or putting it another way, you can assume that 5 to 10 percent of employed personnel will exceed existing limitations and that a very few persons will significantly exceed them. It will be of great advantage to us if we can assure all personnel that the standards which we establish are sufficiently safe so they are positively guaranteed against radiological injury. On this basis I would say that the value of K ought not to exceed 40 percent.

In considering the lower limitations of K, we are concerned with technical problems and must make provisions for the operating efficiency of our personnel. How long can we work in a radiological zone and keep the risk and effort commensurate with the work accomplished? The absorption of radiation is never desirable and should never be permitted unless necessary. But when we get down to a value of K on the order of 10 percent, we begin penalizing ourselves and encumbering the personnel to a point where they cannot work efficiently in areas that are appreciably radioactive. Obviously, the law of diminishing returns must govern. During Operations Crossroads and Sandstone the value of K was on the order of 2 percent. Work in radioactive zones was carefully planned to permit personnel to quickly enter these zones and secure information or equipment of scientific value. Even with this careful planning the work was considerably hampered by the high degree of personnel protection which we maintained. In some instances personnel arriving in radioactive areas were scarcely able to orient themselves to a job before they found it necessary to withdraw. Such operations led to fast Jeep rides over rough terrain where the reading of radiological instruments became inaccurate and sometimes defeated the prescribed precautionary measures. It would be practical in wartime, without serious consequences to personnel, to work in radiological areas well beyond the Sandstone limitations. On occasion the desire for extreme caution leads to more serious hazards of other natures. For example, in the Ammunition Removal Operation on the Bikini vessels after Operation Crossroads, the extreme precautions for personnel involving the wearing of rescue breathing apparatus to protect against possible, but actually insignificant, concentrations of radioactive material in the air led to the amplification of explosive and other types of physical hazards. The poor vision afforded by the rescue breathing apparatus was a contributing source of difficulty. On the battleship Nevada, one man received a glancing blow that could have been fatal from a falling ammunition charge simply because he couldn't see clearly. The injuries actually received in this operation were negligible, but the hazards were potentially great.

There can be a very real danger from increasing our protective requirements too greatly. If we set K at 10 percent, the time will come when a local commander will be more impressed with the inefficiency of his command than with the need for protection against radiation. He will become aware of the fact that radiation within his command is harmless and at the same time he is failing to get a job done because of extreme precautionary measures against radiation. He is likely to kick over the traces and assume that radiation hazards are overrated. He may issue orders that the job be accomplished regardless of the hazards involved. This is about the worst thing that can happen because the hazards are there no matter how intangible they may appear, and they will inevitably take a toll if suitable precautions are disregarded. For this reason the working limitations should be reasonable to a point where the local commander realizes that he must not exceed WMT but that the established value of WMT will allow him to work with the greatest possible freedom. With this in mind it would appear that the value of K could profitably be set at 20 percent and that any value below this would unnecessarily restrict the efficiency of the organization and might possibly hamper the protective measures themselves.

The next problem becomes that of establishing a reasonable value of K somewhere between the upper limitation of perhaps 40 percent and the lower limitation of 20 percent. The major influence in determining the proper establishment of this value would appear to be psychological. No matter how hard we may try to calmly evaluate radiation as a hazard and place it in its proper scale with other forms of military hazards, it has psychological aspects which simply do not fit our normal modes of approach. Let me illustrate this by discussing what I call, for lack of a better term, the "furnace factor."

Suppose, for example, that you approach a group of men with the idea of obtaining a hundred volunteers to crawl through an area where they will be exposed to well-controlled machine-gun fire as a training confirmation. You give them assurance that they will be carefully watched and that the fire will be terminated if any injury to anyone is noted. You would not expect too much difficulty in getting volunteers for this mission during wartime training. "Hope springs eternal in the human breast." There is a possibility that one man may get hurt, perhaps killed, but each man with a faith in his own destiny knows that it will be somebody else, and that he will be safe. Now, to recognize the psychological pitfall introduced by a nonsensory danger, let's change the problem to one in which the fate of every man is pegged to that of his comrade. If a group of men were standing in a blast furnace when the heat accidentally went on, you would expect reasonable uniformity of injury to each man in the group, regardless of whether the flames were devastating or quickly quenched. If a group were standing in the beam of a giant X-ray machine, one would expect no preferential protection. It is hard to find an analogy in conventional warfare, but perhaps we could subject the group under machine-gun fire to a more uniform hazard. Let's change the problem by turning on a battery of flame throwers while the men are in the control zone. Assure them that the heat will be turned off as soon as any injury to personnel is observed. Draw your own conclusions as to how many volunteers you will get for a task like this. In the first example each man has 99 changes out of 100 of survival, whereas in the second instance every man should meet a fate as bad as that of anyone in the group. Whether he gets burned to death or just gets his hair singed, each man is sure that he will be treated just as badly as his companion. This is about what might be expected by personnel working in a lethal radioactive zone and the expectation may prove unpopular. Gamma rays are not respecters of persons. Whether they subject everyone to a withering dose or to an insignificant exposure, they hit everyone in the target area with almost identical effect. To understand the psychological factors which this creates, you must consider the ideas, trivial or otherwise, that run through the minds of your soldiers. They will think about this sort of thing when they are confronted with hazards which they can neither see nor taste nor feel nor smell but which they, nevertheless, know are having physical effect upon them. Such hazards prey mostly upon the mind. The men must have a powerful faith in their commanding officer to work continuously and calmly in the presence of unobservable but certain hazards.

If you hope to get the most out of the men, you will recognize the significance of this intangible but highly important emotional factor and prepare them psychologically for the work in which they are to be employed. One of your strongest talking points in such a psychological campaign will be the assurance that you have held the K factor down to the lowest reasonable value; in other words, that you have virtually eliminated the so-called "furnace factor."

Now let me emphasize once more that we would not expect highly radioactive zones in the average atomic-bomb explosion. Radiological defense concerns itself with readiness for the instances in which such residual radioactivity is found. If radiological defense measures are to be invoked when they are needed then we must prepare for them now by training and equipping personnel to comply with their missions when required. We must expect atomic bombs in future wars. We must expect injury, and it is proper to assume that we will encounter residual radioactivity in some circumstances. Such radioactivity zones will not necessarily contain rates of radiation which would approach lethality under normal working conditions. But we can expect significant dosages.

The areas bombed may be our most important installations—atomic plants, ordnance plants, big industries—the things which we must restore to operation if we are going to carry on the war. If we approach the problem with the assumption that such an area is radioactive and if we put a fence around it and stay out—we are licked! We can, and must, work in radioactive zones. But we must work in them under controlled conditions. We can't go to the commander and say, "Now, there are no hazards in here at all. You are free to work." What we *can* say is: "We would like you to attempt work, but it will be dangerous. You must be prepared to work for limited periods only. There will be over-exposures. For this reason you must have replacements at hand. Exposure records of personnel must be maintained. Personnel must receive qualifying physical examinations, since a limited number of people can thus be separated as undesirable radiological risks for such work."

The technical aspects of radiological defense constitute a field in which much has been done to assist the commander. The radiological defense officers will be important assistants to him. More than 1,000 have already been trained, and we are training about that number yearly in joint courses conducted by the Army, Navy, and Air Force at Army Chemical Center, Treasure Island, and Keesler Air Force Base. These are the personnel who will assist organizationally. They understand the calibration and use of detection instruments and the nature and evaluation of radiological hazards.

In this discussion, my references to radiation have implied gamma radiation, the long-range killer, which I consider the most dangerous type of radiation. There are others. For example, alpha and beta emissions will have great significance where lingering toxic effects are to be feared. Underwater bursts or surface bursts may contaminate areas with a multiplicity of fission products in the form of radioisotopes. After a period of time, rates of decay will eliminate certain fission products as significant hazards and the readings which are obtained from some types of detection instruments may become negligible. Such fission products may be superseded by others as principal hazards. Under circumstances where sabotage might be involved, the most serious hazards may be hardest to detect. Such complexities give rise to serious problems of personnel and material decontamination and point up the need for special personnel and equipment.

Protective equipment consisting of masks and disposable clothing for the workers may be indicated. Careful monitoring of radioactive areas and supervision of workers will be necessary to prevent operations in "hot spots" of radioactivity. It may be necessary to have field laboratories and special technicians for the analysis of radioactive materials and to determine the freedom from toxicity of air, water, and food. Training of specialized personnel has commenced and development is under way on all necessary types of instrumentation and equipment. It is hoped that the current service research program may lead to some simplification in the complex material requirements of radiological defense.

Radiological defense is a responsibility of command. The establishment of a wartime military tolerance will provide a planning guide for the military commander. It will enable him to complete requirements for timely replacement of personnel. It will be a guide in protecting personnel against external radiological hazards but will not be an absolute limitation placed upon the commander. Under conditions where personnel must travel through or work in atomic areas with the only alternative being destruction from other causes, any established tolerance would serve no purpose.

Realizing that no simple guides will prove unfailing and that complete reliance upon specially trained advisers is not always expedient, the current program for radiological defense training is aimed at service-wide indoctrination.

Over and above our training programs, there will be many operational problems for which there is no simple scientific or textbook approach. Our training program admittedly needs stiffening along these lines. There is very little realistic experience upon which to base standard operational procedures. We have had atomic-bomb bursts under conditions of war in Japanese cities but the residual radioactive conditions were lacking. We have had a series of atomic-bomb tests but these were not associated with the disaster conditions to be expected in wartime. We can say one very definite thing about radiological hazards. We may not have them associated with every atomic-bomb burst. We may not, and we probably won't. But when we do have them, the radiation hazards will invariably be associated with cataclysmic destruction resulting from the atomic bombing in the form of vast numbers of injured personnel; fires; broken water mains, gas lines, and electric wires; disrupted communications and the probable failure of logistic support; and panic. Our operational development must be guided by the fact that our radiological defenders, to accomplish their primary mission, must work in the presence of these other complex problems.

The normal employment for radiological defense personnel will be in areas of sublethal contamination. Our efforts must be to determine what we can do, rather than what we cannot do in these areas. We can and will work in them when there is cause. We will not sacrifice vital industry and war plants simply because they are contaminated with a radiation level of 10 or 20 roentgens per day. Under such conditions, a well-trained staff group will be indispensable in prescribing the working conditions, techniques, lengths of exposure, protective devices, and decontamination procedures and in providing adequate supervision.

We should not disregard the possibility that many of our personnel who are trained for radiological defense may be called into disaster areas even in event of high-altitude atomic bursts. There may be no need and no reason for this other than the fact these people have had a special training course.

We must not leave our problems of operational development unsolved awaiting a hurried solution under conditions of actual warfare. Future atomic tests should be very useful for developing our standard operational procedures and organizations and military personnel should be employed in radiological defense work in these tests to increase our service experience. These tests are few and far between and are sometimes limited to specialized objectives. Since they fall short of the disaster conditions toward which our planning must be pointed, it seems vital that there be operational development within the services. We have a great deal to do in properly evaluating the air reconnaissance of radiological areas, in determining the value of helicoptors for radiological survey, in perfecting remote and projectable telemetering instruments and techniques and in completing time studies and work planning and on-the-spot orientation methods for such conditions. We have a great deal more planning to do in the matter of provision of adequate and timely personnel replacements in radiologically hazardous areas.

Operational development work will provide a continuous testing of textbook training and prevent stagnation of training doctrine. Without it our training in theoretical aspects can advance only to the limit of the most recent physics text and in its practical aspects to the limits of the last information which has emanated from atomic tests.

No discussion of this nature could be complete without some reference to civil defense. Since most of us have families, we are naturally interested in this problem. The armed services are responsible for effecting their primary military missions in wartime and will, in general, be unable to effect civil defense. Recognizing this condition, it is proper that the military should keep out of civil defense as much as possible. This will confront the Civil Defense Organization with the responsibility of growing up to meet its own probelms. It would be sheer folly, however, to overlook the fact that civil defense will have a great influence on our capabilities to wage war. The next war may very well be won or lost on the home front. Recognizing this, we are trying to do what we can in support of civil defense without complicating it. Our research programs are pointed toward developing equipment which will be as useful to the civil defenders as to the military. The field of radiological defense, from its inception, has been a universal field with universal language, equipment, techniques, and training. It is a military goal to increase our readiness in equipment and trained personnel so near to the service requirements that if called upon in emergency we can dispatch radiological defense personnel to any point necessary. To this end we have initiated a truly joint training program with the Army, Navy, and Air Force, turning out of their own schools joint student groups who have been trained in joint curricula under joint staffs so that in emergency they can be banded together quickly and work together with intelligence and precision as they did in Operation Sandstone.

CHAPTER 8

LOCAL ORGANIZATION AND TRAINING FOR RADIOLOGICAL DEFENSE

Section I. INTRODUCTION

The advent of radiological warfare has made necessary the development of new training programs for service personnel. A great number of personnel must be indoctrinated and trained and many levels of training set up for the different degrees of responsibility. The purposes of these programs will vary from a mere indoctrination lecture for the psychological reason of mitigating fear, to a highly technical course to prepare Radiological Defense Engineers. The periods of training vary and range from as little as 1 hour to as long as 3 years.

The military importance for training service personnel in radiological defense is evidenced by the fact, that among the responsibilities of the Armed Forces Special Weapons Project are included the following:

Furnishing assistance to the commandants of service schools, through appropriate channels, in preparing courses and training instructors, and collaborating in the preparation of atomic energy instructional material within the Army and Navy Departments.

Furnishing material to responsible governmental agencies to assist in the education of the public on the military uses of atomic weapons, particularly in connection with civil defense measures.

It is a responsibility of the Armed Forces Special Weapons Project to furnish instructional material and assistance in the training programs. Implementation of the training requirement is left to the individual service school and military command.

Effective radiological defense demands that all personnel be thoroughly trained in the particular part each is to execute if and when an attack comes. The amount of instruction should be commensurate with individual responsibilities. The responsibilities, in turn, will be determined by the type of organization for radiological defense. The over-all defense organization having been established and the responsibility of each position determined, the training program then can be planned. The object of the training progam therefore should be to prepare personnel to qualify for the various positions in the defense organization.

Section II. ORGANIZATION AND TRAINING

The basic Department of the Army policy on radiological defense organization and training is set forth in Department of the Army Plan for Radiological Defense dated 27 March 1950 (app. VII).

This basic policy recognizes the fact that the enemy employment of atomic or radiological weapons may present a simultaneous need for many, or all of the countermeasures normally applied against other types of enemy action and in the interests of effecting the maximum utilization of personnel and facilities, the Army organization for radiological defense will be included, wherever possible, within the framework of existing organizations dealing with command, training, logistical support, and operational control measures designed to counter enemy action.

The functions of the present Army organization described in FM 21–40 for defense against chemical attack will be expanded to include radiological de*fense, thus providing specially trained personnel at* all levels of the military structure to assist and advise commanders in radiological defense planning and *action.*

At the various echelons, this expansion of the functions of the chemical defense organization provides for enlarged duties to staff chemical officers (staff radiological defense officers) and unit gas personnel. At division and higher headquarters, radiological defense duties are delegated to the staff chemical officer who serves as the technical adviser to the commander and staff in such matters. At headquarters of all communications zone and zone of interior service elements, radiological defense duties are delegated to the staff chemical officers, who function similarly to the staff chemical officer at the higher echelons of command. At installations these duties are delegated to the post chemical officer who serves as technical adviser to the post commander. Below division level these duties are assumed by the unit gas officers (unit radiological defense officers). Each combat or service brigade, regiment, battalion, company, or similar unit has at least one qualified unit gas officer and at least one qualified alternate.

The radiological defense organization with respect to unit gas noncommissioned officers (unit radiological defense noncommissioned officers) parallels, in general, that of the unit gas officer. The unit gas noncommissioned officer assists the unit gas officer at the various lower echelons.

Section III. RADIOLOGICAL DEFENSE TRAINING PLAN

The inclusion of radiological defense instruction throughout the Army training system will provide three general levels of training—basic indoctrination, military technical training, and advanced theoretical education. The scope of instruction within each of these levels will vary in accordance with the requirements of different operational and staff positions. Detailed programs of instruction covering the three levels of training will be coordinated by the Armed Forces Special Weapons Project.

BASIC INDOCTRINATION

This level of training will include the basic, nontechnical instruction in radiological defense measures and techniques which must be imparted to all commissioned and enlisted personnel of the Army to enable them to perform their assigned duties efficiently in the presence of radiological hazards.

The basic indoctrination of commissioned personnel is being effected through the incorporation of a minimum of 2 hours of basic radiological defense instruction in the curriculum of the United States Military Academy, and a minimum of 6 and 8 hours, respectively, in the basic and advanced courses of the special service schools as specified in SR 350-110-10.

The indoctrination of higher ranking officers is accomplished through the incorporation of a minimum of 6 hours of radiological defense instruction in the curricula of the joint colleges (National War College, Industrial College of the Armed Forces), the Command and General Staff College, and the Armed Forces Staff College. Indoctrination of senior officers is conducted at Sandia Base. Quotas for this course are controlled by Assistant Chief of Staff, G-3.

The indoctrination of enlisted personnel will be accomplished through the incorporation of basic radiological defense instruction in all individual and unit training programs, and by means of appropriate manuals and training literature which will be developed for this purpose.

MILITARY TECHNICAL TRAINING

This level will include the training of the majority of the personnel who will be required to staff the Army radiological defense organization and perform the technical operations involved, and will be accomplished through the establishment of suitable courses of instruction to train qualified staff radiological defense officers, unit radiological defense officers, unit radiological defense noncommissioned officers, radiological defense monitors, radiological instrument repairmen, and certain categories of Army Medical Service personnel.

Staff Chemical Officer (Staff Radiological Defense Officer)

Inasmuch as the duties of the staff chemical officer now have been expanded to include those of radiological defense, the training previously required to qualify these officers for their jobs also must be expanded.

The training of new officers for chemical staff duties presents no particularly difficult problem and all current and future training programs for these officers include the additional instructional material required to fulfill their expanded mission. However, the training qualification of present staff chemical officers, to include radiological defense, is not so easy, because of varying educational and professional background, and the impracticability of training them at one place at one time. Hence, for a period of time during which the transition from a limited qualified chemical officer to a fully qualified chemical officer is completed, a number of temporary training programs are currently in operation in addition to normal radiological training programs.

Among the courses presently available to fully qualify Chemical Officers for their expanded duties are the following:

Chemical officers special orientation course. A 4 weeks' course designed to give chemical officers sufficient orientation on bacteriological warfare, radiological defense, and new developments in chemical warfare so they may meet the new requirements. The course of 140 instructional hours consists of approximately 35 hours on BW, 22 hours on CW, and 72 hours on RD. This course of instruction will be utilized, insofar as practicable, to qualify all Chemical Corps officers who are above the level of the Advanced Course of the Chemical Corps School, either by virtue of age or by having been accorded constructive credit equivalent for the course.

The 6 weeks' Joint Radiological Defense Officers' Course conducted at the Chemical Corps School, Army Chemical Center, Maryland; at the Air Force Technical School, Keesler Air Force Base, Biloxi, Miss.; and at the United States Naval Damage Control Training Center, Treasure Island, San Francisco, Calif., will be utilized to qualify Chemical Corps officers for their expanded functions and to train Chemical Corps specialists for technical job positions or special assignments within the Chemical Corps which require a degree of training more advanced than that provided for in the Advanced Course of the Chemical Corps School, but less advanced than that provided for radiological defense engineers. Other Army agencies having job positions which require a degree of training more advanced than that provided for at the unit radiological defense officer level but less advanced than that provided for radiological defense engineers may utilize this course to satisfy their individual requirements.

Unit Gas Officers (Unit Radiological Defense Officers)

For lower echelons, a 6 weeks' course is planned for late 1950. This course, designated as Unit Gas Officers Course, will contain approximately 50 hours of instruction in radiological defense.

For Reserve officers, it is contemplated that the additional training needed to establish minimum qualifications will consist of especially designed correspondence courses in conjunction with the annual 2 weeks' active training duty periods. The complete cycle of training to cover a 3-year period.

It is contempalted that unit gas officers of regiments and separate battalions will be trained at division, corps, and Army schools in a 4 weeks' course which will be integrated with biological and chemical material, and that officers filling similar positions in organic battalions and at company (separate and organic) level will be trained in division schools and unit training centers.

Unit Gas Noncommissioned Officers (Unit Radiological Defense Noncommissioned Officers)

For noncommissioned gas officers a 6 weeks' course, Unit Gas Noncommissioned Officers Course, is currently offered at the Chemical Corps School, Army Chemical Center, Maryland. This course includes approximately 48 hours in radiological defense. They will receive sufficient training in radiological defense measures and techniques to enable them to assist unit gas officers in the performance of their duties, and to supervise monitoring operations in their unit areas.

It is contemplated that unit gas noncommissioned officers of regiments and separate battalions will be trained in division, corps and Army schools in a 4 weeks' course which will be integrated with biological and chemical material, and that individuals filling similar positions in organic battalions and at company (separate and organic) level will be trained in division schools and unit training centers. In either instance, mobile training teams may be utilized as an alternate means to accomplish this training.

Radiological Instrument Maintenance Personnel

The training of enlisted personnel in the field and depot maintenance and repair of radiation detection instruments will be conducted at the Signal School, Fort Monmouth, N. J., and the Signal Training Center, Camp Gordon, Ga. As soon as instruments become available, 100 hours of such instruction will be included as part of the Radio Repairman Course. It is estimated that a large number of radio repairmen will be given this training each year in those instruments which will be in general use throughout the Army and the Navy.

Radiological Defense Engineers

The training of Regular Army officers to qualify as radiological defense engineers is presently being conducted in accordance with current directives.

Training of Medical Personnel

The Surgeon General is at present conducting a 5-day orientation course in the medical aspects of nuclear energy at the Army Medical Department Research and Graduate School, Army Medical Center, Washington, D.C. In addition, a 3-week orientation course on the medical aspects of radiological defense will be started in 1951 at the Medical Field Service School, Brooke Army Medical Center, Fort Sam

Houston, Tex. This course will be more advanced than the 5-day course and will be open to members of the United States Army Reserve and Federal agencies, as well as to all Army Medical Service personnel.

All officers and enlisted men who are attending technical courses of instruction at the Medical Field Service School, Brooke Army Medical Center, Fort Sam Houston, Tex., are given varying amounts of orientation in radiological defense.

It is anticipated that medical specialists will be given military technical training in the clinical aspects of radiation injuries starting in 1950.

The advanced training of selected medical officers in the medical aspects of radiological defense and in the pathological and clinical aspects of radiation injuries is at present being provided in a course of post graduate study ranging from 6 months to 1 year at selected civilian universities, followed by 3 to 4 months of field training at an installation of the Atomic Energy Commission of the Armed Forces Special Weapons Project. While occupying positions dealing with radiation, additional periods of training will be given in certain individual cases. The Atomic Energy Commission Medical Fellowship Training Program will be utilized in this advanced training of radiological defense medical officers.

Highly selected MSC officers are being given post-graduate training in radio-chemistry, biology, and allied medical fields pertaining to radiation, followed by a period of field training in an installation of the Atomic Energy Commission or the Armed Forces Special Weapons Project.

DEPARTMENT OF THE ARMY PLAN FOR RADIOLOGICAL DEFENSE

The Army Plan for Radiological Defense was approved 29 December 1949 by the Chief of Staff, Department of the Army. The implementation of the programs will be directed by the Chief, Army Field Forces. The necessary training aids and instruments will be issued on an automatic basis by the Chief, Army Field Forces. It is anticipated that current procurement schedules now in force call for delivery of instruments and training literature to Army Activities during the last quarter of 1950. The Army Plan for Radiological Defense is included as appendix VII.

CHAPTER 9

NONMILITARY APPLICATION OF ATOMIC ENERGY

The old adage, "Ill blows the wind that profits nobody" is demonstrated by the application of man's knowledge of atomic energy. The terrific pressure brought to bear on the research, development, and manufacture of the atomic bomb under wartime conditions resulted in a tremendous increase in the technical information and skill in nucleonics. The primary objective during the war was to deliver the greatest military weapon the world has ever seen. But even then some of the beneficial outcomes of nuclear research became apparent. Today not only the present utility of this new "age of nucleonics," is evident but also the many humane applications of atomic energy which may soon be within the realm of accomplishment.

Section I. THE APPLICATION OF RADIOACTIVE ISOTOPES IN RESEARCH AND INDUSTRY

The use of the phenomenon of radioactivity in research and industrial testing is not new. As early as 1912, Hevesy made use of this property of some elements to investigate the solid state of lead. Within the last few years, however, this technique has been greatly expanded. The use of radioactive atoms, or as they are more commonly called "tagged atoms," in industry and research is called tracer technique. The fundamental idea in using this method is to mix some radioatcive atoms among the stable atoms of the test substance. Inasmuch as radioactive atoms radiate and can thus be detected, they indicate the position and amount of the test substance in the body of the material. The use of this technique depends upon a generous source of radioactive isotopes, which is now available since stable isotopes may be irradiated within the atomic reactor pile and made radioactive artificially. Table IV lists the most frequently used isotopes for research purposes. Over 80 percent of the new industrial usage of reactor-generated radioactivity recorded by the Atomic Energy Commission was in the tracer technique. A few of the many uses of the tracer technique are given in the following section:

Section II. THE APPLICATION OF RADIOACTIVE ISOTOPES TO THE STUDY OF PHYSICAL PHENOMENA

Calibration of ultra microbalances with alpha-active material. The mass of a high alpha emitter can be more accurately determined by counting instruments than by weighing on conventional balances.

Use of tracers in electroplating baths to determine concentration of an ion. The depletion of minor constituents in electroplating baths might be followed with a radioisotope.

Use of tracers in the analysis of a product from a reaction mixture of known composition. Analysis of a product for impurities may be made by the addition of a radioisotope to the reaction mixture in a definite proportion to the weight of the element or elements sought.

Use of tracers to study the cause and cure of foaming and priming. Tracers can be used to study the cause and cure of industrial foaming and priming, the effect of different dissolved salts and antifoams.

Distribution measurements of textile finishes. By the use of tracers, studies have been made of the distribution of lubricant on rayon fiber in order to evaluate the role of the lubricant in subsequent dying and spinning operations.

Flow studies of components of process operations. Modifiers in process operations, such as plastic manufacture, might be followed, giving information on mechanism and value of such materials.

Process rate studies. Rate studies on industrial processes can be of value in understanding of the processes. Tracers have wide application in this field.

Product control. Any reaction involving inorganic materials where freedom from impurities is important. Examples are—analytical reagent manufacture, pigment manufacture, ceramic manufacture.

Use of tracers in distillation. Wide application in all phases of the study of the distillation.

Use of radioisotopes in metering fluid. Radioisotopes can serve as metering fluid in the usual method of dilution measurements and have a decided advantage in case of analysis.

Use of tracers to determine the effectiveness of scrubbing gases. Radioactive tracers simplify the analytical problems involved.

Use of tracers in the analysis of equilibrium data and the relative efficiency of various absorbents.

Use of tracers to determine separation efficiences in centrifugation, filtration, etc.

Determination of the homogeneity of a mixture after various times and degrees of agitation.

Determination of the settling rate of a suspension.

Use of tracers in process control to determine concentration of an ion in continuous operation. Middle processing baths — cleaning, fire-growing, coating; electroplating baths — minor constitutents; rayon processing baths—minor constituents; textile processing baths; pulp and paper manufacture; and gas-reacting system.

Measurement of linear velocity of liquid flow with tracers. The linear velocity of liquid flow in a pipe can be measured by timing the successive appearance of activity at two points along its length. The method is of special value where circumstances are such that sampling is impossible; the activity can be measured through the pipe walls.

Use of tracer to determine the effect of tracer impurities upon the physical properties of synthetic fiber.

Use of radiocarbon to study copolymerization.

Cracking of petroleum oils with intense radiation. Low-temperature cracking of petroleum may be possible.

Friction and wear tests—gasoline engine.

Mining. Tracers used to study many mining processes, such as flotation, permeability, well logging, petroleum recovery, etc.

Quality control. Thickness of silicone film on rubber—adhesion; height gage—cupola level; and thickness gage—metallic and plastic sheets.

Determination of tarnish resistance of silver plate.

Determination of transfer of printing ink from printing plate to paper.

Section III. THE APPLICATION OF RADIOACTIVE ISOTOPES TO THE STUDY OF BIOLOGICAL PHENOMENA

The body, in its functioning, uses a variety of substances. Proteins—complex molecules manufactured in the body from amino acids; carbohydrates—essential fuels for the body; liquids—the fats and fatlike substances, which are a source of energy and a component of certain hormones; nucleic acids, all have a part in making up the cells that form the substance of the body.

In addition to these, other important substances include the various blood constituents and the electrolytes—such minerals as potassium, sodium, and calcium.

Full understanding of the behavior of many of these substances must await the time when their basic nature and activity has been determined by research. An example of the attack upon these problems is the studies on the essential constituents in the blood. The blood, containing plasma and cells, is the circulating distributor of chemicals and oxygen throughout the body, and lends itself to biochemical study because of the ease of obtaining samples.

Anemia is a disease characterized by a deficiency in the quality or quantity of the blood. Certain types of this disease do not yield to dosages of iron. Treatment with hormones has been found to correct all phases of anemia in the pituitary cases except for the deficiency in the hemoglobin. Scientists of the School of Medicine at Boston University extended their experiment into the protein fraction, and other constituents of hemoglobin. They are now preparing to use radioactive carbon to trace this phase of blood metabolism.

At the Radiation Laboratory, University of California, red blood cells are taken from the body, labeled with radio phosphorus and then reinjected to determine the speed with which the labeled substance mixes with the total blood. The rate of disappearance of sodium and iodine from the blood stream was measured by tracers also, thus making possible a satisfactory measurement of such factors as blood volume, the amount of fluid outside of cells, total body water, and total body sodium.

Iron and zinc both enter importantly into the metabolism of red and white blood cells. Using radioactive metals to follow "trace" elements, groups of physicists, chemists and physicians, collaborating in studies of anemia and luekemia at the Massachusetts Institute of Technology, Brookhaven National Laboratory, and the Harvard Medical School, are discovering the activity of these "trace" metals which may contain important information on these diseases.

At the University of Rochester, radiocarbon was used to label lysine, which is indispensable to life and growth. Further studies suggest many facts concerning proteins and mineral salts. The changes in body chemistry have been studied at Harvard Medical School, Peter Bent Brigham Hospital, and Massachusetts General Hospital.

The effects of infectious diseases upon the organs are being studied by scientists at Bowman Gray School of Medicine, Wake Forest College, where radiophosphorus is used to study the formation of certain liver fats which contain phosphorus, also.

A study of nucleic acids and nucleoproteins, which could be properly designated at the keystones of life, indicate that in this field there is hope of increasing the scientific understanding of the cancer problem. The activity of derivatives of nucleic acid in the system is being studied at the University of Colorado.

Further experiments have been made into the acid processes of diabetes, and improvement in the treatment of this disease soon may be available through the use of radioisotopes.

In addition to serving as a tool for basic research into life processes, radioisotopes have proved valuable in laboratory and clinical studies of diseases, and are being used in diagnosis and in treatment.

At Yale University School of Medicine, radiotagged elements are used in the study of the thyroid and the sex glands. Harvard Medical School is using radiophosphorus to locate brain tumors during surgery, and radioactive iodine to relieve pain in two types of heart disease—angina pectoris and congestive heart failure.

Ohio State University, the University of California Radiation Laboratory, and the University of Illinois are each conducting experiments designed to determine the value of radiocobalt in cancer research and treatment, as a substitute for radium. Cancer research, sponsored by the Atomic Energy Commission, has the dual purpose of learning the basic structure and processes of cells, and studying the radiation effects in man.

Organic components of nucleic acid have been prepared in the laboratory at Memorial Hospital, Sloan-Kettering Institute, and labeled with isotopes to be used in cancer research. A great number of experiments undertaken at Argonne, Oak Ridge, the National Cancer Institute, and Huntington Memorial Hospital, have contributed to the understanding of how cancer arises.

Experimenters are irradiating normal chemicals of the body to find whether they form cancer-producing chemicals. The way in which metal beryllium causes cancer of the bone is being studied at Huntington Memorial Hospital.

Other experiments are directed toward learning more about the effects of some isotopes which can be valuable in treatment of disease, but also dangerous because of the way in which the body stores them.

Research using radiocarbon has been conducted at Argonne, Southern Research Institute, and the Universities of Minnesota and California. Scientists are now attempting to direct certain isotopes, including radioiodine so far used almost exclusively in the treatment of the thyroid gland and cancers spread from this source, to other possible sites of cancer in the body. A compound, stilbamidine, has been synthesized with radiocarbon at the Radiation Laboratory, University of California.

The use of radiophosphorus in the treatment of certain blood disorders, including leukemia, at New England Deaconess Hospital, Western Reserve, the University of Chicago, and many other hospitals, indicates that it may be helpful in cases of leukemia that have become resistant to X-ray treatment, and also in the treatment of stomach and skin cancers.

Figure 35 shows the injection of a radioisotope into a cockroach preliminary to a study being conducted at the Medical Division, Army Chemical Center, Maryland.

Section IV. PARTICLE ACCELERATORS

Nuclear reactions are caused by particles shot like bullets into the nuclei of atoms. Nature supplied the first atomic bullets, the particles emitted by such radioactive elements as radium and polonium. Today various powerful atom-smashing machines yield high-speed alpha particles, protons, deuterons, beta particles, and gamma rays. The atomic pile is now the main source of neutrons. Atom smashers work on the principle that the charged particles—the atomic bullets—can be accelerated and guided by electric and magnetic fields.

Figure 35. Injection of radiosotope into cockroach.

Van De Graaff Accelerator

A source of high voltage which has been used to accelerate charged particles for nuclear experiments is the electrostatic generator developed by Van de Graaff. This device consists essentially of a continuous belt made of some insulating material such as silk, linen, or paper, which passes over two pulleys. One pulley is at ground potential and is driven by an electric motor; the other pulley is mounted inside a hollow metallic cylinder or sphere of large radius of curvature. The hollow body is insulated from the rest of the apparatus. In the operation of this generator, an electric charge obtained from a comparatively low voltage source is sprayed on the portion of the belt which is moving upward from the lower pulley. This charge is carried up by the belt into the hollow sphere where the charge is removed to the sphere by means of a fine metallic brush.

In this generator a continuous stream of charges is transferred by the belt from a low voltage source to the insulated metallic sphere. The potential of a sphere depends directly upon the quantity of electricity which resides on its surface. The conditions limiting the amount of charge which may be put on a sphere are the nearness of other objects, such as the walls and ceiling of the laboratory, and the breakdown of the air near the sphere due to the intense electric field around it. Electrostatic generators have been operated successfully with the spheres raised to potentials as high as 2.5 million volts above ground potential. In some generators the voltage of the belt charging device was as low as 10 kilovolts.

In recent designs, the electrostatic generator has been built completely inside of a steel container in which the air is maintained at a high pressure, sometimes as high as 150 pounds per square inch. At high pressures the air can withstand stronger electric fields before breakdown occurs. Also, since the air is contained in a steel tube it may be dried and cleaned, thus permitting steadier operating conditions.

The Linear Accelerator

The linear accelerator accelerates nuclear particles by giving them repeated "kicks" with a high-frequency alternating voltage. At any instant, adjacent electrodes of the accelerator are oppositely charged. A nuclear particle is accelerated into an electrode and coasts inside it, emerging just as the alternating voltage reverses. The particle then is repelled by this electrode and attracted by the next one, thus receiving a "kick" as it crosses the gap between them. This process continues down the length of the tube. Since the particles go faster and faster down the tube,

Table IV. Some Typical Non-Military Uses of Radioactive Isotopes

ELEMENT	ISOTOPE	HALF-LIFE	RADIATION	TYPICAL USES
Calcium	$_{20}Ca^{45}$	180 days	Beta and gamma	Research on fertilizers, bone formation.
Carbon	$_{6}C^{14}$	4700 years	Beta	Study of photosynthesis, plant physiology, carbohydrate utilization in animals.
Chlorine	$_{17}Cl^{36}$	103 years	Positron and beta	Research on the physiology of plants and animals.
Gold	$_{79}Au^{198}$	2.7 days	Beta and gamma	Treatment of leukemia.
Iodine	$_{53}I^{130}$	12.6 hours	Beta and gamma	Treatment of thyroid cancer and hyperthyroidism.
Iodine	$_{53}I^{131}$	8.0 days	Beta and gamma	
Iron	$_{26}Fe^{55}$	4 years	Beta	Study of anemia, diseases of plants, blood circulation. Friction studies.
Phosphorus	$_{15}P^{32}$	14.30 days	Beta	Treatment of leukemia, polycythemia vera, skin cancer. Study of blood circulation and metabolism.
Potassium	$_{19}K^{42}$	12.4 hours	Beta and gamma	Research on diseases of the heart and nervous system.
Sodium	$_{11}Na^{24}$	14.8 hours	Beta and gamma	Study of blood circulation, cell function, congestive heart failure.
Sulfur	$_{16}S^{35}$	87.1 days	Beta	Research on plant physiology, proteins.

the accelerating electrodes are progressively greater in length.

Cyclotron

Another device for producing high energy particles which has come into fairly common use in the cyclotron developed by Lawrence and Livingston. It consists essentially of a short hollow cylinder divided into two sections. Each section usually is referred to as a "dee" because of its resemblance to the letter D. These dees are placed between the poles of a very large electromagnet. The cyclotrons now in use have magnets whose pole pieces are from 30 to 60 inches in diameter; the diameters of the dees are approximately the same as those of the pole pieces. The dees are placed in another metal cylinder, and the whole assembly is placed between the poles of the electromagnet so that the magnetic field is perpendicular to the base of the cylinder and parallel to its axis.

The Betatron

An entirely new type of X-ray tube was developed in 1941 by D. W. Kerst. This tube is called a betatron. In the older type of X-ray tubes, the electrons which strike the target acquire their energy by the application of a high voltage between the filmament and the target. In the betatron, the electrons acquire their energy by the action of the force exerted on them by the electric field which accompanies a changing magnetic field. One tube in operation in 1946 accelerated electrons so that they had energies up to 100 Mev when they struck the target and produced X-rays and present designs range to about 1 billion electron volts. These X-rays are used in nuclear experiments.

In the operation of the betatron, electrons from the heated filament are injected into the circular or doughtnut-shaped tube by applying a difference of potential between the filament and the plate. The electrons are focused with the aid of a grid. When an alternating magnetic field is applied parallel to the axis of the tube, two effects are produced—an electromotive force tangential to the electron orbit is produced by the changing magnetic flux and gives the electrons additional energy; a radial force due to the action of the magnetic field, which is perpendicular to the electron velocity, keeps the electron moving in a circular path. The magnetic flux through the orbit has to be chosen in such a way that the electrons will move in a stable orbit of fixed radius. The electrons make several hundred thousand revolutions in this circular path while the alternating magnetic field is increasing in intensity from zero to a maximum, that is, during a quarter of a cycle. With each revolution they gain additional energy. When the electrons have acquired the desired amount of energy, a capacitor is discharged through two coils of wire, one directly above and the other directly below the stable orbit, producing a sudden addition to the magnetic flux. This destroys the condition for the stability of this orbit and the electron beam moves out to larger radii until it strikes the back of the injector which acts as the X-ray target.

In the operation of the 20 Mev betatron, about 15 to 20 kilovolts are applied to the injector, and electrons are injected into the tube for only a short time, about 8 microseconds, when the magnetic field just starts increasing. The magnetic field alternates 180 times per second, but the electrons are accelerated during only one quarter of a cycle or 1/720 of a second. The tube is kept on the vacuum pumps continuously.

A new atomic big-gun, the world's largest betatron, has just gone into action at the University of Illinois, Urbana-Champaign, Illinois, capable of flinging electron particles of electricity at 300,000,000 electron volts to produce X-rays and other effects.

Manufacturing the meson particles naturally found in cosmic rays is one of the jobs it is expected to do. As big brother to smaller atomic machines using the decade-old invention of Prof. Donald W. Kerst, it is more powerful than lesser betatrons that are used in inspecting chunks of metals and treating deep-seated cancers.

The new betatron is one of the largest atom-smashers of any sort actually operating, although larger billion electron volt machines are under construction.

The Synchrotron

The synchrotron accelerates electrons inside a large, circular glass tube, placed in the field of a ring magnet. The magnet is powered with alternating current. During the initial period of the accelerating cycle, the magnet accelerates the electrons to nearly the speed of light, just as in a betatron. Then, a slightly greater velocity is given the electrons by an accelerating electrode built inside the circular tube and connected to a high-frequency oscillator. With this slightly greater velocity, the electrons increase tremendously in mass and energy. During the entire period of acceleration, the increasing magnetic field of the magnet holds the electrons in a circular path in the tube, and at the proper instant they are deflected to strike the target. In some synchrotrons, the accelerating electrode is replaced by a resonant cavity, through which the electrons pass.

The Chain-Reaction Pile

Although it is not generally regarded as an atom smasher, the chain-reaction pile is actually the most effective and important form of particle accelerator. What is more, a pile produces neutrons—particles which are very effective in causing nuclear reactions, but which cannot be directly accelerated in any standard atom smasher. A typical pile is a large concrete-enclosed mass of graphite and natural uranium. The uranium undergoes a controlled chain reaction, liberating vast numbers of free neutrons in the process. The material to be bombarded is placed in the pile, or a hole is opened in a wall of the pile and a beam of neutrons will emanate from the hole and fall on the material to be irradiated. The operation of the chain-reaction pile is described in chapter 2.

Table V summarizes the characteristics of the machines discussed in the foregoing paragraphs.

Table V. Comparison of Particle Accelerators

Accelerator	Particle*	Highest energy of operating equipment in Mev†	Highest energy of equipment under construction in Mev	Remarks
Electrostatic accelerator	Any charged particle	5	12	Capable of precise energy control and collimation. Limited to the lower energy range because voltage is applied in one step.
Rectifiers or transformers	Any charged particle	2		Similar to the electrostatic accelerator.
Cyclotron	p d α	10 20 40	 30	A reliable and economical accelerator in the medium energy range. Limited to energies of a few 10's of Mev by the relativistic mass increase.
Betatron	e	100	1,000	For electrons only. A simple machine in the medium energy range but limited by radiation loss to several hundred Mev.
Synchrocyclotron	p d α	350 190 380	450	This machine overcomes the energy limitation of cyclotron but becomes uneconomical above 500 Mev. Beam intensity is lower.
Linear accelerator	p e	32 25	68 1,000	The energy is unlimited. It has the advantage over magnetic machines that the beam emerges in a well-collimated bundle with a small energy spread.
Synchrotron	e	335	1,000	Raises the energy limitation of the betatron.
Proton synchrotron	p	6½	8,500	The energy limit is the economic one but it is higher than that of the synchrocyclotron.

* Particles: p, proton or hydrogen nucleus; d, deuteron or heavy hydrogen nucleus; α, alpha particle or helium nucleus; e, electron.

† Mev, 10^6 electron volts.

Section V. NUCLEAR POWER

Whether nuclear energy as a commercial source of power is feasible and when it might be available are presently being carefully considered by scientists, engineers, and industrial experts. No firm commonly accepted conclusions have been reached. But one authority makes this optimistic statement: "There is no mystery about atomic energy that good engineering cannot solve."

The material that follows presents different points of view and includes data which has been arranged into tables and charts for the convenience of the instructor in presenting the material visually. See figures 36 to 41 inclusive and table VI.

Ultimate output of atomic energy in this country may be as great or greater than present output of coal power "and will operate at a lower cost, at least as far as fuel expenditure is concerned." That was the Atomic Energy Commission's view in 1948 on power prospects, provided that favorable assumptions are made about two things—

That the cost of uranium does not rise markedly in the future because of forced resort to lower-grade ores; and that the theoretical possibilities of "breeding" atomic fuel can be realized in engineering practice. The latter means building atomic reactors which are highly efficient so that when they consume fissionable materials they will, at the same time, produce an equal or greater amount of new fissionable material by transmutation of non-fissionable uranium or of thorium.

If unfavorable assumptions are made, that the cost of uranium will rise and that breeding will prove impracticable, then atomic power could compete with coal power only in regions where cost of transportation from the mine is a determining factor.

This view on economic prospects from atomic power is much the most optimistic which has ever come from official sources. It puts the official Atomic Energy Commission position much more nearly in line with private estimates that the ultimate cost of atom power would drop somewhere between hydro and steam.

The new position appears in the fourth semiannual report of the AEC. It is presented as a report to AEC of the Commission's General Advisory Committee. This source is particularly significant, since the advisory committee generally has been considered as the group in the government most pessimistic on power possibilities. Actually, the best informed authorities do not believe that atomic power will ever be able to compete with coal in cost.

As to time scale, the advisory committee still is rather conservative. It points out that two reactors to produce token electric power should be completed within 2 or 3 years.

One of these is the air-cooled natural-uranium pile at Brookhaven Laboratory on Long Island, due for completion in the fall of 1950; it will produce some power from the heat of its cooling air but not even enough to run the blowers which drive the cooling system.

The other is a reactor of advanced design at the Argonne Laboratory in Chicago. This will be a fast-neutron pile using enriched fuel and cooled by liquid metal. It will run at a high temperature and will produce power in something approaching commercial quantities, though at nothing approaching commercial costs. Construction of this reactor was discussed for a year and a half before it was finally authorized.

Building on experience with these two units and their successors, the advisory committee thinks, "fairly practical reactors that might be useful for special purposes" should be available within a decade.

In about 20 years, under favorable circumstances, a "considerable portion of the present power supply of the world" might be replaced by nuclear fuel, the committee believes.

Nuclear energy will not contribute any very large amount of power to the world during the next 10 years. That is the opinion of all well-informed scientists now working in this field, according to Sir John Cockcroft, director of Britain's Atomic Energy Research Establishment. The reason is that four major technical problems must be solved. These are—

1. *The "fuel" problem.* Investigations so far have shown that, while natural uranium piles which could generate power as a byproduct are technically feasible, their "fuel" efficiency at present is so low that they would not be economical. Natural uranium piles "burn up" only a very small proportion of the uranium at present. The fuel problem thus becomes the socalled "breeding" problem—finding a way to utilize the greater part of the uranium "fuel." Until this is done, present resources of uranium will be insufficient for large-scale nuclear power.

2. *The metallurgical problem.* Finding materials, better suited to withstand high temperatures, which can be used in construction of piles.

3. *The "combustion" problem.* Finding an efficient way to process the nuclear fuel used in the pile, which includes removing the intensely radioactive ash from the fuel safely and economically.

4. *The "ash disposal" problem.* Getting rid of the large quantities of radioactive ash that would be produced by the sizable number of nuclear power stations required to supply the world.

Section VI. NUCLEAR ENGINEERING

The following article by Major General Kenneth D. Nichols, USA, appeared in Nucleonics, July 1949.

The normal engineering approach to the solution of problems is as applicable in the field of nuclear engineering as in any other branch of engineering. Some of the nuclear engineering problems encountered by the Manhattan District, a few of those presently encountered by the Atomic Energy Commission, and some of the steps that have been taken by universities to meet the need for engineers trained to handle these problems will illustrate this fact.

In the early days of the Manhattan Project, primary problems involved not only science but, even to a greater extent, engineering and industrial management. Research and development had to be completed, and organizations obtained (or built up) to design the necessary production plants, construct them, and then operate them for plutonium and uranium-235 production. In addition to research and development, a considerable amount of engineering was necessary if a practical bomb was to be developed. The scientists on the project at that time recognized the existence of typical engineering problems but few of them realized the complexity or the magnitude of the engineering that would have to be devoted to their solution before the project could be accomplished.

I was fortunate to be able to observe how many of the problems that confronted the Manhattan District were solved. To find engineering contractors to design the production plants was the first problem. Our selection was Contractor Corporation. Although we realized that they could not handle all the problems, we needed a vehicle to make engineering studies on everything, so their original contract was made very broad and comprehensive. Shortly after the selection of contractor, it was obvious to us and to the physicists in Chicago that a great deal of chemical engineering had to be done if a chain reaction pile for production of plutonium was ever to prove itself practical.

The chemical problems associated with the plutonium project, for instance, were tremendously underestimated. As contracting officer, I sat down to do some estimating with the Chicago physicists, the michrochemists who knew what was to be known about the chemistry of plutonium that had been derived from less-than-milligram lots, and with engineers from du Pont. How many dollars' worth of plant would be necessary to develop a practical semiworks for the chemical process? Three million dollars was the figure arrived at—although most of us thought it might be on the high side.

One month later du Pont had gotten into the problem enough to realize that neither two nor three million would touch the problem. Not only that, they felt the whole project needed a thorough engineering review to determine if the many engineering problems involved, not only in the plutonium project but in the U^{235} and weapon development projects as well, could be solved in a reasonable length of time. As a result, a committee consisting essentially of engineers was set up. It did its work between September and November 1942. They made preliminary cost estimates that turned out to be reasonably accurate, and recommended the types of organizations that were necessary to design, construct, and operate the plants involved in the Manhattan Project.

On the U^{235} end of the project the task involved engineering problems equally as difficult as those on the plutonium project. The basic scientific work on the physical separation of U^{235} and U^{238} was extraordinarily well in hand, but in this case too the research on the supporting chemistry lagged behind. In the electromagnetic plant, for instance, there were those early days when no matter how much material was put into the production pipeline nothing seemed to come out and the project's leaders were joshed for attempting to produce vanishing quantities of U^{235}.

We were faced with the single chemical problem of separating U^{235} from associated gunk. Because of the small quantity of U^{235} and the extremely large quantities of gunk, consisting of a mixture of many other elements, here, too, normal chemical engineering did not apply. A precision of recovery was required that far exceeded normal production standards, but production engineers, assisted by research chemists and research engineers, finally devised and set up the necessary production line technique.

As a means of defining the need for engineers in the atomic energy field I could enumerate other examples and give more adequate recognition to the many industrial firms that formed a part of the team that put over the Manhattan Project. However, I prefer to draw on history only to the extent I have done to illustrate how the engineering approach for evaluating the task and organizing for the job was successfully applied.

The Present and the Future

Out of our experience on the Manhattan Project and in planning for the development of atomic power it has become clear that the future of atomic energy depends primarily on how well engineers do their job. Let us look at some of the specific problems involved in nuclear engineering. In a pile, whether it be for production of plutonium for bombs or for production of commercial power, the engineer is faced with new and difficult problems with which he has had little experience; and during the war he had practically none. At the present time army engineers have the experience derived during the war, but most engineers lack additional educational training that permits them to solve these new problems without learning new principles required by the atomic era.

Shielding. Take, for example, shielding against radioactivity necessary wherever you have a chain reaction or radioactive materials. Here engineers were and are faced with strange requirements. One material might stop one type of radioactivity but not another. Moreover, some materials merely convert one type of radioactivity to another. Health physics is involved and there is little industrial background for making the necessary statistical studies.

Gadgeteering and remote control. One aspect of shielding is protection of the workmen. Another equally important aspect is the remote control and maintenance problem. In the chemical processes, or in the working of the pile itself, the process equipment must be controlled and maintained by remote control methods. Intensive gadgeteering was and is necessary for doing this type of work. At Hanford, complete chemical processes had to be capable not only of operation by remote control but also of maintenance by remote control. Some of the gadgetry involved is what we are now depending upon as a delaying factor in other nations' attempts to make atomic weapons.

Chemical recovery. Also involved in nuclear engineering is a need for precision of recovery not normally encountered even in the light chemical industry. The value of plutonium or U^{235} is so high that extremely high percentage of recovery is necessary in any ancillary chemical process in the production of power if such power is to be competitive with other sources of power. Not only is such precision chemical engineering complicated by the need for remote control apparatus, but also the transmutation from one element to another of the attendant products is a complicating factor. The control of radioactive wastes, both liquid and gaseous, must be done to a degree not generally recognized by other industries. Many millions have been spent at Hanford in the control of these liquid and gaseous wastes and, if commercial power is ever to be practicable, even greater effort must go into this problem in order to secure an economical solution. The chemical engineering involved in the production of power or in the production of plutonium is the major problem that must be more efficiently solved if we are ever to have competitive atomic power.

Heat exchange. Here we have problems that are beyond the experience of most of the experts in this field. In the heat exchange problem, we are faced with taking a tremendous amount of heat out of a very small volume. The problem is further complicated by radioactivity. We must consider the nuclear properties of the coolants used for transmitting power from source to machine. We must consider both the effect of the coolant on the nuclear reaction and the effect of the reaction on the coolant. The temperatures involved are such that liquid metals may be the only suitable coolants. When we combine all these problems with the known characteristics of materials, we find ourselves working with some very nasty materials that introduce added problems of safe handling.

Materials and metallurgy. Throughout the pile we are confronted with engineering problems concerning materials and metallurgy. The materials used in the piles must meet functional and structural requirements and must stand up against the high temperatures involved. Not only must they stand up against temperatures with which we have insufficient practical experience, but they must also have the proper nuclear properties. Here again the materials may affect the nuclear reaction, or the effects of the nuclear reaction on these materials may be such that the physical properties of the materials, such as the structural strength, conductivity, or molecular structure, are charged to such an extent that they no longer fulfill their basic missions. Here the research engineer must work with the physicists, for a tremendous amount of work must be done to determine the nuclear properties of ordinary structural materials and to develop new materials that can be produced in quantity and have the proper nuclear properties.

Economic problems and industrial safety. Dependable methods and equipment must be developed that are far beyond our normal industrial standards. It is costly to maintain equipment by remote control or abandon it when something goes wrong. If the economic problems of atomic power are to be solved, great dependability must be built into even the ordinary equipment, greater than is required for the equipment of any other industry.

Other engineering problems involved pertain to industrial safety. Unfortunately, many of the scientific personnel involved in the development of nuclear energy do not have practical experience in industrial safety. The result is that unusually high standards have been set. Industrial safety engineers will eventually have to solve this problem and get it on a practical scale if we are to have economical nuclear power plants.

Industrial uses for radioactivity. In solving all of these engineering problems the solution must be based on the needs of the operator or producer. A theoretical solution is of little value if it cannot be applied on an industrial scale. The engineer, by training and tradition, is accustomed to meeting the needs of the industrial operator in like problems pertaining to other fields. He has bridged the gap between the scientists and the industrialists in such other engineering fields as electrical engineering, chemical engineering, metallurgical engineering, mechanical engineering, power and other, and there is no reason why he cannot render the same service in the field of nuclear engineering.

More engineering problems are attached to the application of radioactivity or the use of radioisotopes to engineering research for developing chemical engineering processes or for developing better metallurgy. Radioactive materials are being used in the petroleum industry. Other uses undoubtedly will be developed as experience is acquired.

The Universities' Problem

The problem presently confronting our universities is to determine what courses should be introduced to train engineers and scientists adequately for the development of atomic energy. It is not my intention to cover the needs of additional scientific training in our universities. However, I would like to make certain suggestions concerning what might be done in the field of engineering education to qualify our graduate engineers for handling nuclear engineering problems. Just one course in our engineering schools will not be the answer; what is necessary is the introduction of nuclear engineering courses in the several fields—civil, mechanical, electrical, and chemical engineering. Such courses in their respective fields should stress the problems of heat exchange, metallurgy and materials, chemical engineering, gadgetering or remote control, and industrial safety, all handled from the standpoint of how nuclear physics affects the solution of these problems when applied to nuclear engineering.

Most universities have already tackled the problem of training graduates for atomic energy development. Some progress has been made. Cornell, Princeton, Chicago, and practically every other large university have introduced courses in the field of nuclear engineering or engineering physics, but too many of them have stressed the research approach rather than the engineering approach.

One university's course leading to a master's degree in science, there is no question, stresses the physics, metallurgy, and chemistry involved in nuclear energy. It covers all of the scientific or research fields but it apparently does little toward giving the student the engineer's concept of how to approach a typical engineering problem. The universities are making a mistake if this is to be the main educational effort. If it is the main effort, it is up to the educators in engineering to correct it.

Greater progress can be made if we train engineers to handle nuclear problems just as we have trained chemical engineers to handle chemical problems involved in the engineering, design, construction, and operation of production plants. Instead of giving a few courses in engineering to a student who is essentially a physicist, a chemist, or a metallurgist, greater emphasis should be placed upon giving students who have a basic engineering education, either civil, chemical, electrical, mechanical, the principles of physics, and the problems of nuclear engineering involved in the particular field of engineering. For example, a chemical engineer would major in nuclear chemical engineering, or a civil engineer major in nuclear civil engineering, each taking the necessary additional courses to qualify him for work in the field of atomic energy.

The Societies' Contribution

The American Society of Mechanical Engineers is assisting in this problem. In recent meetings of their atomic energy committee, they have discussed the need for a greater number of engineers in the atomic energy field. They have offered to assist the AEC in trying to procure more engineers with industrial and commercial background for this work. More engineers and engineering organizations will be necessary as time goes on if the basic work of the scientists presently engaged in the problem is to be properly developed and applied. The American Society of Mechanical Engineers is also preparing a glossary of all terms involved in nuclear engineering as a first step in the education of engineers. They are, in addition, entertaining the idea of making proposals for the placing of engineers in atomic energy work.

How University Personnel Can Help

In attempting to develop proper education courses, secrecy and government control of the atomic energy field may appear to be limiting factors. However, there is plenty of information available upon which an effective start in the field of education can be based. A means that bears recommendation is for more university engineering departments to seek contracts from the AEC or with its contractors for the development of the engineering research in this field. Also, more professors should seek temporary employment with the AEC and its contractors so that they can get first-hand information about the problems involved. They will then be in a better position to determine the basic educational courses in the field of physics and physical chemistry required and the revisions and additions necessary to our more standard engineering courses.

Our educational efforts in the field of nuclear engineering should be devoted primarily to giving supplementary education in the fields of physics and radioactivity to engineers rather than trying to give a little engineering to scientists. Although it is recognized that both approaches are necessary, the engineering approach to the problems of atomic energy will do far more towards expediting the solution of the remaining problems than the scientific approach. There is no mystery about atomic energy that good engineering cannot solve.

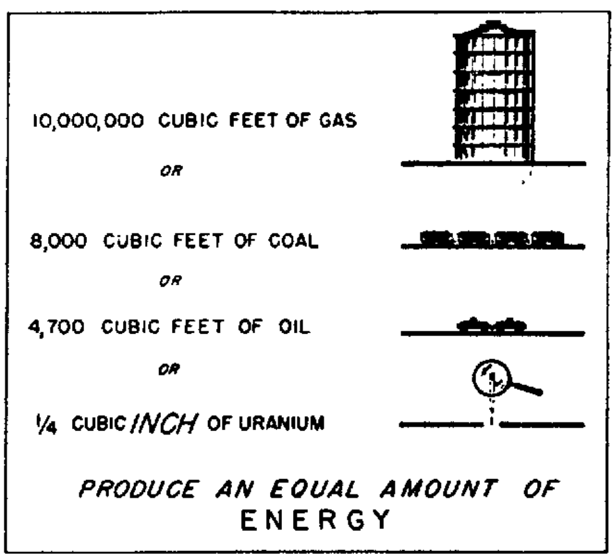


Figure 36.

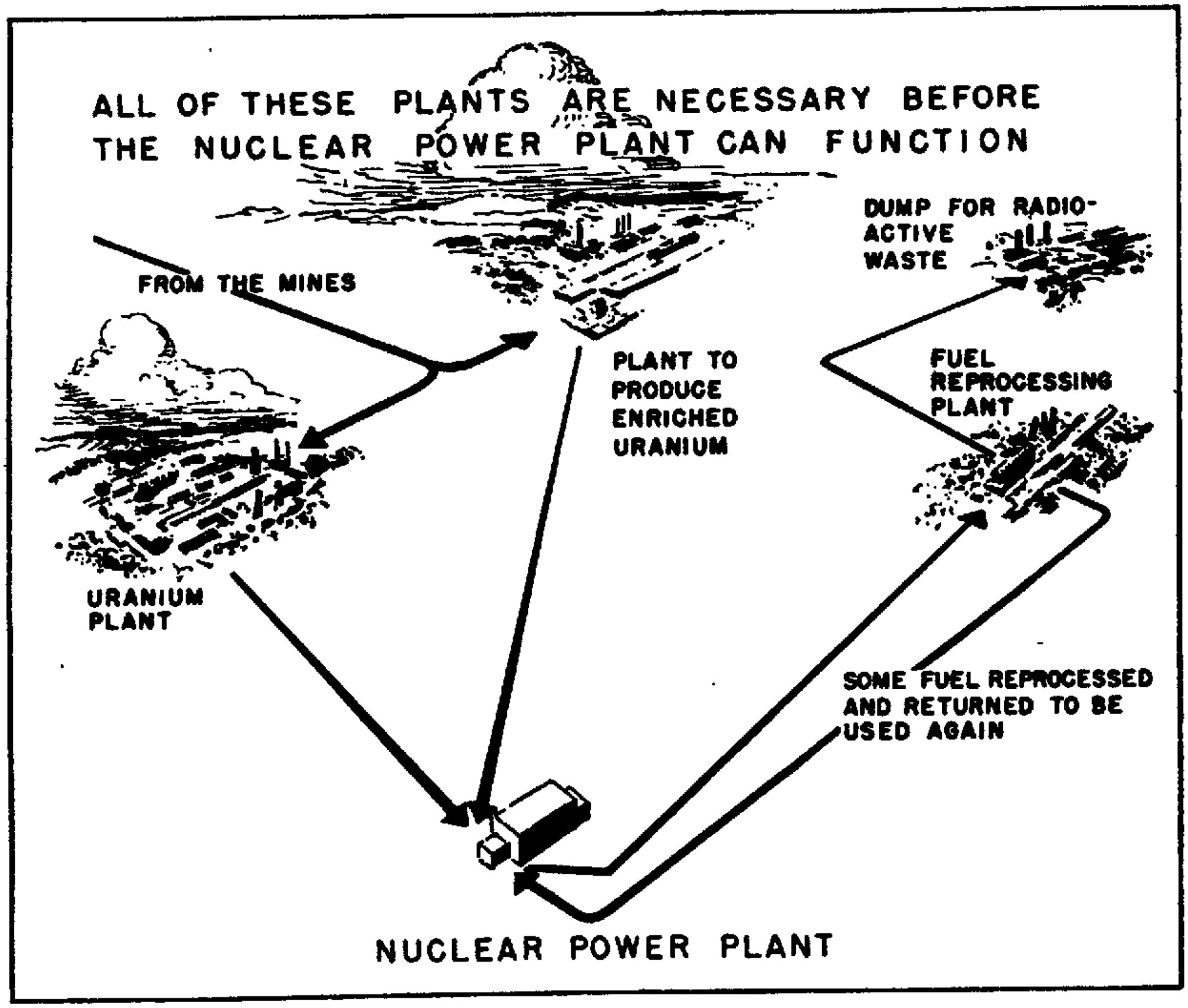

ALL OF THESE PLANTS ARE NECESSARY BEFORE THE NUCLEAR POWER PLANT CAN FUNCTION
FROM THE MINES
PLANT TO PRODUCE ENRICHED URANIUM
DUMP FOR RADIO-ACTIVE WASTE
FUEL REPROCESSING PLANT
URANIUM PLANT
SOME FUEL REPROCESSED AND RETURNED TO BE USED AGAIN
NUCLEAR POWER PLANT

Figure 37.

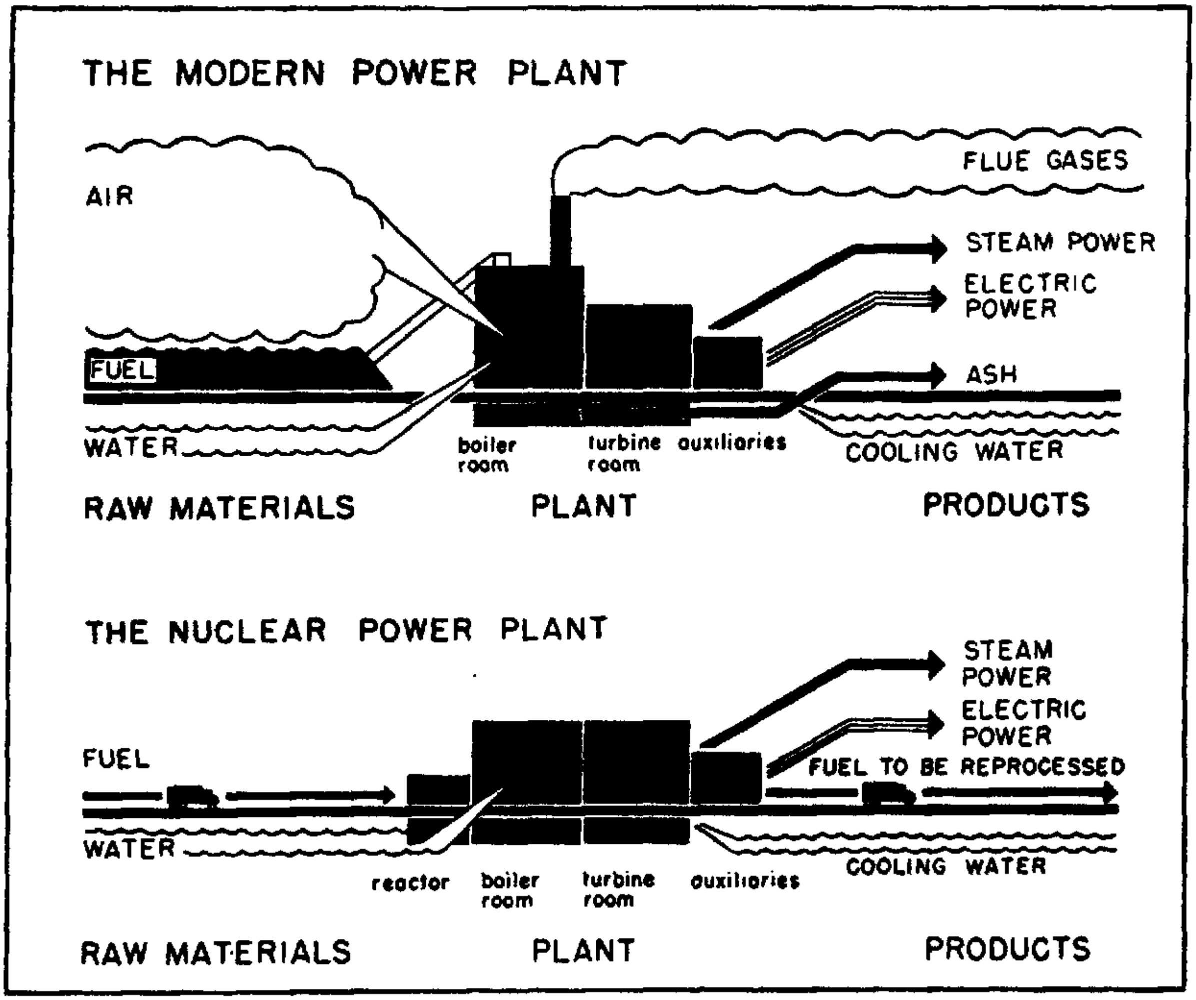

THE MODERN POWER PLANT
AIR
FLUE GASES
STEAM POWER
ELECTRIC POWER
FUEL
ASH
WATER
boiler room
turbine room
auxiliaries
COOLING WATER
RAW MATERIALS
PLANT
PRODUCTS
THE NUCLEAR POWER PLANT
STEAM POWER
ELECTRIC POWER
FUEL
FUEL TO BE REPROCESSED
WATER
reactor
boiler room
turbine room
auxiliaries
COOLING WATER
RAW MATERIALS
PLANT
PRODUCTS

Figure 38.

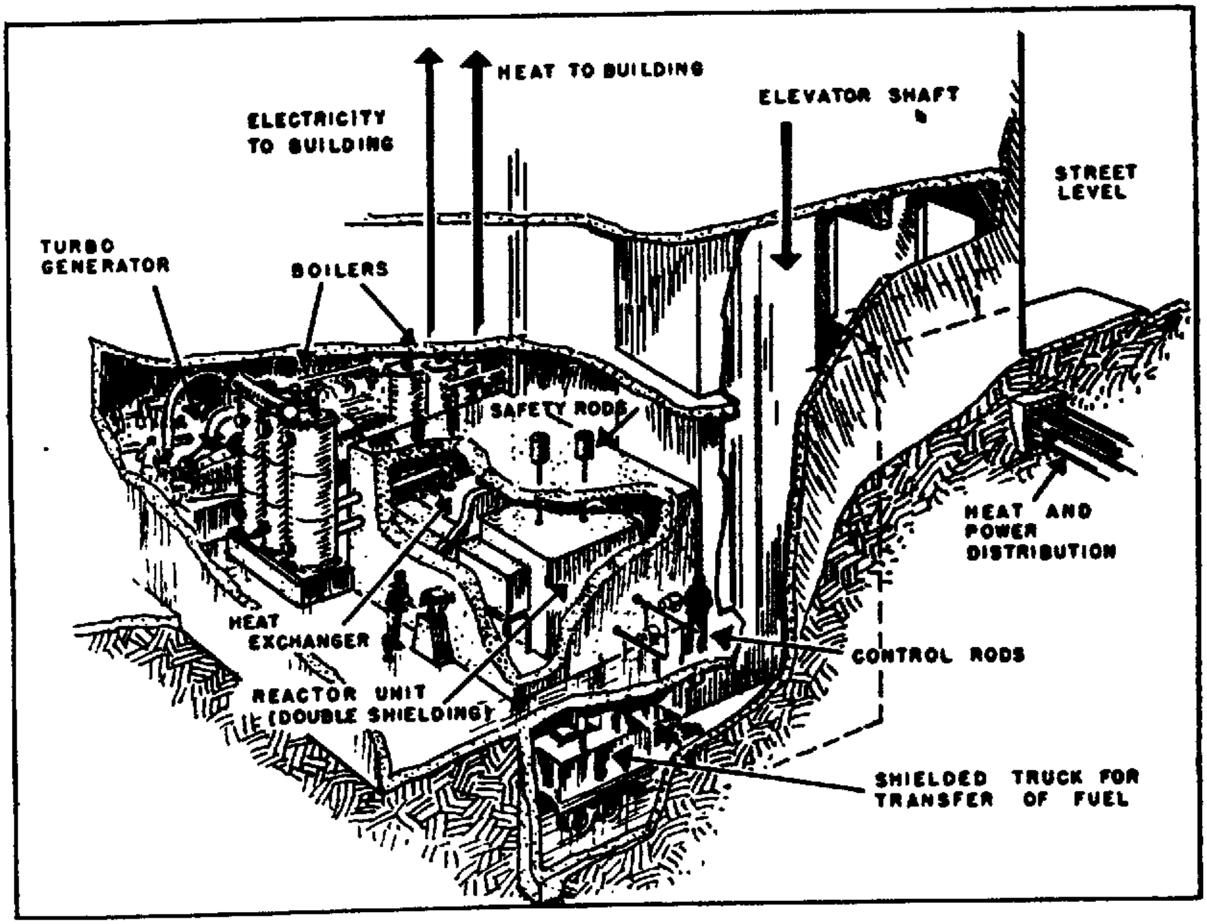
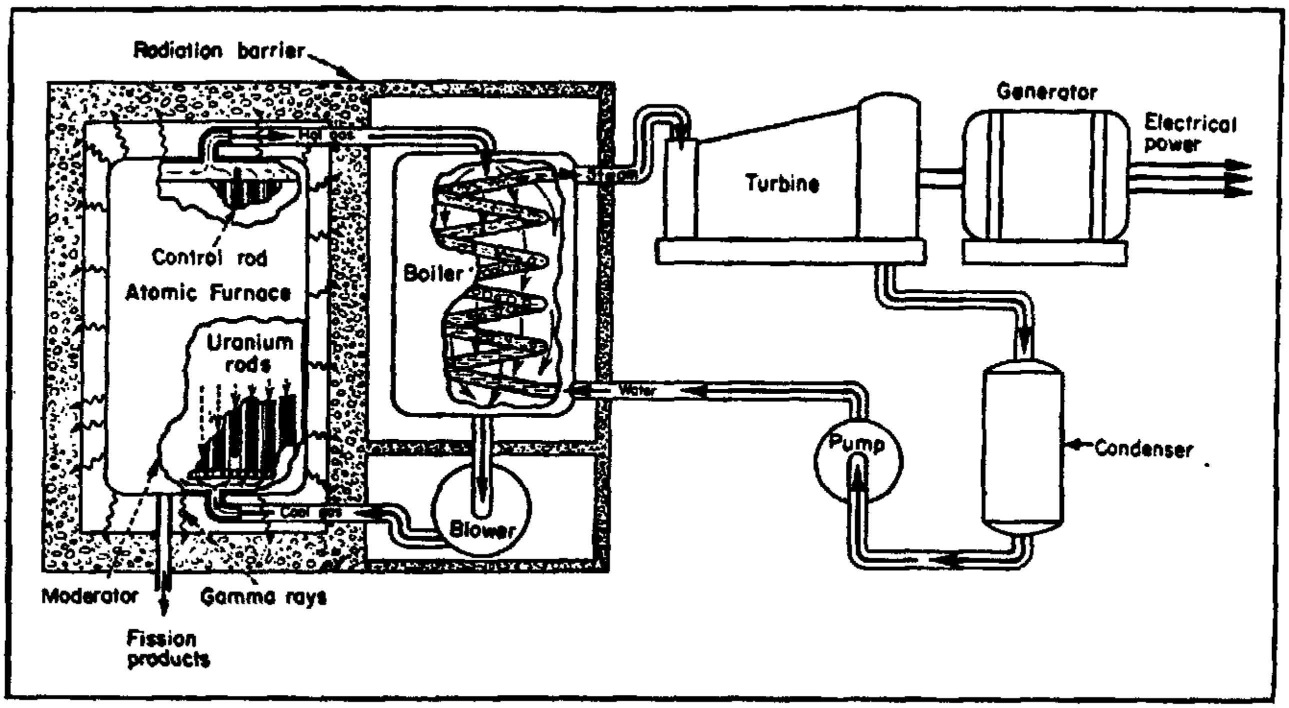

HEAT TO BUILDING
ELECTRICITY
TO BUILDING
ELEVATOR SHAFT
STREET
LEVEL
TURBO
GENERATOR
BOILERS
SAFETY RODS
HEAT AND
POWER
DISTRIBUTION
HEAT
EXCHANGER
CONTROL RODS
REACTOR UNIT
(DOUBLE SHIELDING)
SHIELDED TRUCK FOR
TRANSFER OF FUEL

Figure 39.



Schematic Diagram of Oak Ridge Power Installation. The sketch indicates that the first nuclear power plant includes all the components of a conventional power central station, i.e.; heat source, boiler, turbine generator, and condenser. A gas, presumably He, CO_2, SO_2, or some other with low σ at thermal energies, is indicated as the coolant for this heterogeneous unit. This gas flows in cylindrical annuli about the uranium rods, one of which is shown partially withdrawn to serve as a control rod. The amount of shielding required around the boiler unit is purported to be only about one-third that around the "atomic furnace." In order to remove the fission products it would be necessary to remove the uranium rods and process chemically rather than by means of the idealized method indicated in the sketch.

Figure 40.

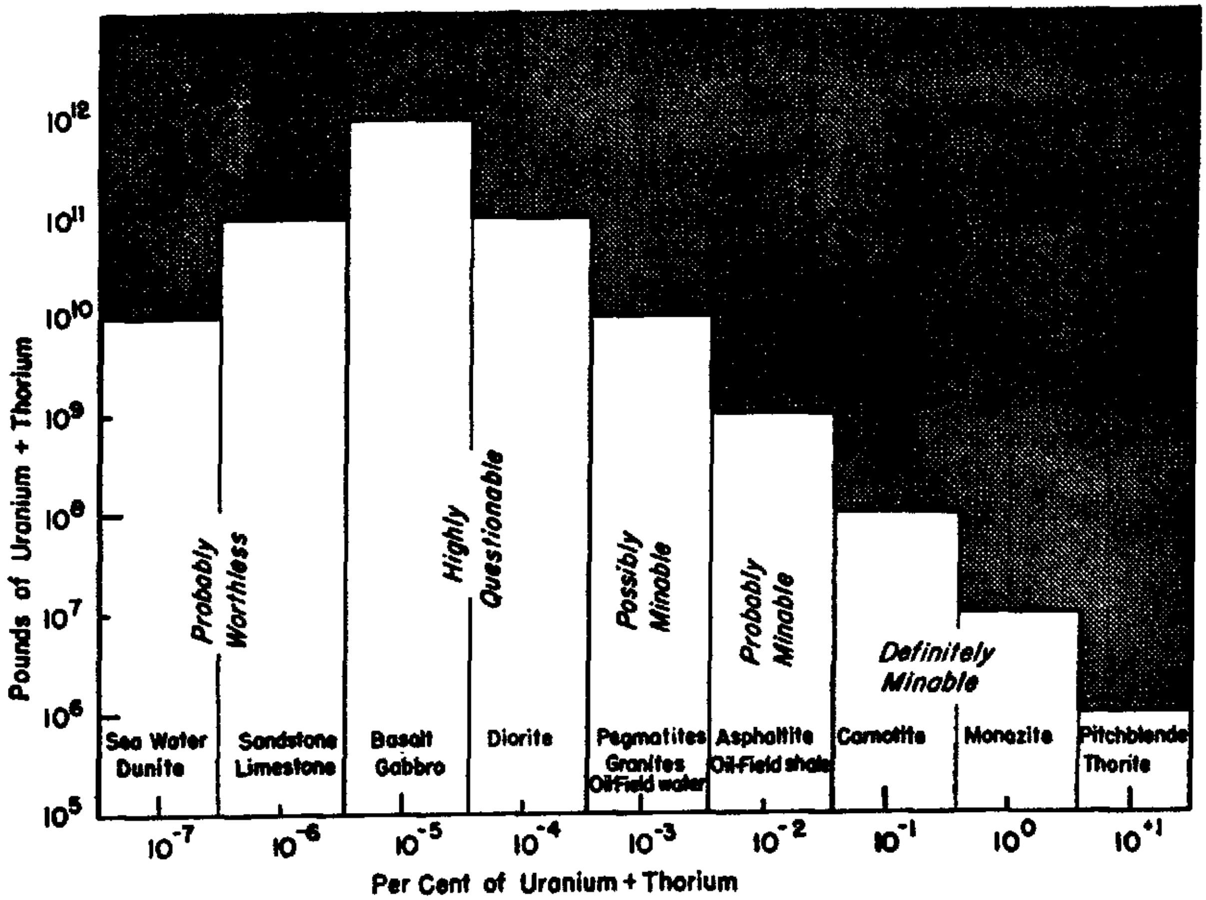


Figure 41. Estimated United States reserves of fissionable materials.

Table VI. Sources of Energy per Annum (1941 Basis)

	World			United States			
Source	Energy in 10^{12} kwh	Production in 10^{6} tons	Equivalent U in lbs	Energy in 10^{12} kwh	Production in 10^{6} tons	Equivalent U in lbs	% of World
Solar	1.2×10^{6}	---	120×10^{9}	18,000.	---	2×10^{9}	1.6
Coal.	17.5	2,200	175×10^{4}	4.4	550	44×10^{4}	25.
Petroleum	4.4	510	44×10^{4}	2.7	310	27×10^{4}	61.
Natural gas	1.0	130	11×10^{4}	.88	110	9.8×10^{4}	88.
Water Power	.42	---	4.2×10^{4}	.12	---	1.2×10^{4}	29.
Nuclear Power	.0066	---	660	.0065	---	650	99.
Total	23.	2,840	2.34×10^{6}	8.1	970	0.82×10^{6}	

APPENDIX I

BIBLIOGRAPHY

The purpose of this bibliography is to suggest a nucleus of available current publications on the general topics of a nuclear physics, atomic energy, and radiological defense around which to start a library useful to officers of the armed services and others interested in atomic energy. It is intended to assist instructors in preparing their lectures, and the material listed has been examined and carefully evaluated on the basis of usefulness and availability.

The subject literature is expanding rapidly, and no attempt has been made to compile an exhaustive list. Each item includes a short annotation so that selection may be made according to individual interests and needs.

All the material listed cannot be furnished by the Department of the Army; however, some items can be obtained by official request through normal channels. Most of the items can be purchased commercially.

Section I. MILITARY AND GOVERNMENT PUBLICATIONS

There are, in ever increasing quantity, a number of publications issued by various departments and branches of the Department of Defense, as well as other departments of the Federal government, available through official channels to the radiological defense officers. In some cases, these publications include a detailed bibliography of other available material. Below are listed only a few of the general and key publications recommended as a start in building an up-to-date reference library.

1. *Radiological Defense Manual, Volume I,* Armed Forces Special Weapons Project, National Military Establishment, 1948. A general technical presentation of the various topics deemed essential for radiological defense officers and others. A working knowledge of basic physics and elementary algebra is an asset though not essential. Available through Army channels.

2. *Radiological Defense, Volume III,* Armed Forces Special Weapons Project, 1950. The latest volume in a series of publications issued by this agency. This volume contains a number of topics written by specialists and experts covering the general aspects of atomic explosion, medical effects, and command problems. A "must" volume for all military commands. Available through Army channels.

3. *Atomic Energy and Radiological Defense,* Department of the Air Force, AFTRC Manual 52-355-1, April 1949. An excellent well-illustrated easy reading presentation of the essentials of atomic energy and its relationship to radiological defense. The historical point of view is stressed.

4. *Handbook of Radioactivity and Tracer Methodology,* A. F. Technical Report 5669, USAF, Air Matériel Command, Dayton, Ohio. A rather comprehensive multilith publication covering many phases of radioactivity, prepared by a group of specialists headed by William Siri, University of California.

5. *Catalogue of Radiac Equipment,* Navy Department, Bureau of Ships, NavShips 900,141. An illustrated catalogue of radiac instruments used by the Navy, including a general description and characteristics of gear. References the instruction handbooks for each instrument.

6. *Manual of Radiological Safety,* Navy Department, BuMed and Surgery, NavMed P-1283. Prepared especially for medical officers, it contains considerable material on general nuclear physics, in addition to the medical aspects. There is a section on Navy Radiological Safety Regulations and excerpts of the regulations for the transportation and shipping of radioactive materials.

7. *Shipyard Industrial Radiological Manual,* Navy Department, BuShips. The purpose of this multilithed volume is to serve as a guide to shipyards and repair activities to enable them to evaluate the various features of the industrial radiological problems of materials, organizations, procedures, and personnel.

8. *Radioactivity Units and Standards*, Reprinted from NUCLEONICS, October 1947. (Available through Isotopes Division, Oak Ridge, Tenn.) A small pamphlet explaining in detail the more important units and standards of radioactivity.

9. *Selected Bibliography on Atomic Energy*, Technical Information Division, AEC, 1948. (Available from Superintendent of Documents, 15 cents.) A bibliography of selected references on various aspects of atomic energy including peacetime and military applications.

10. *A General Account of the Development of Methods of Using Atomic Energy of the United States Government* (available from Superintendent of Documents, 40 cents). The above is the official title of what is more familiarly known as the *Smyth Report*. It tells the story of the administration of the development of the atomic bomb, gives the names of cognizant personnel and sufficient technical explanation to appreciate the terrific difficulties overcome. Every officer should read this report. (Obtainable in a stiff-backed edition with photographs from Princeton University Press at $2.00.)

11. *Department of Defense Special Texts*, Radiological Defense Series, Chemical Corps School, Army Chemical Center, Md.

Review of Mathematics and Physics (Army—RDS-1A; Navy—NavPers 10851; Air Force-RDS-1A). Contains part of Mimeo 187, "Review of Mathematics and Chemistry" (Rev. 10 May 48) and Mimeo 185, "General Physics" (5 Oct. 48).

Handbook for Radiological Defense Subcourses (Army—RDS-1B; Navy—NavPers 10852; Air Force—RDS-1B). Replaces Mimeo 145, "Mathematical Tables" (1 Sep. 48).

Atomic Structure of Matter (Army—RDS-2A; Navy—NavPers 10853; Air Force—RDS-2A). Contains part of Mimeo 187, "Review of Mathematics and Chemistry" (Rev. 10 May 48).

Nuclear Physics (Army—RDS-3A; Navy—NavPers 10854; Air Force—RDS-3A). Replaces Mimeo 190, "Nuclear Physics" (Rev. 1 Apr. 49).

Table of Isotopes (Army—RDS-3B; Navy—NavPers 10855; Air Force—RDS-3B). Replaces Mimeo 131, "Seaborg Table of Isotopes" (9 May 47).

12. *Chemical Corps School Mimeographs* for use in Radiological Defense Courses.

- Mimeo 135—*Control of Radioactivity Hazards* (28 Aug. 47) (Reprinted from Chemical & Engineering News, Vol. 25, No. 26, Jun. 30, 47).
- Mimeo 159—*Staff Plans* (1 Sep. 49).
- Mimeo 203—*Electron Tubes and Amplifiers* (Apr. 49).
- Mimeo 204—*Radiation Detecting Devices and Their Uses* (1 Sep. 48).
- Mimeo 209—*Radiological Defense Training Programs* (3 Oct. 49)
- Mimeo 379—*Lecture Notes on Explosion Phenomena, Monitoring and Fall Out* (1 Mar. 49)

13. *Nucleonics for the Navy*, Department of the Navy, NavPers 10850, February 1949. This is a revision of the special edition of the Navy's *All Hands* covering Operation Crossroads and radiological defense, but greatly enlarged. Very well illustrated and somewhat more technical than reference No. 2. Has a particularly good section on radiac instruments.

14. *The Effects of Atomic Bombs on Hiroshima and Nagasaki*, The United States Strategic Bombing Survey, The Manhattan Engineer District, 30 June 1946.

15. Public Law 585, 79th Congress, *Atomic Energy Act of 1946* Senate Publication Section, Library of Congress, Washington, D.C.

16. Army Regulations, AR 380-5, *Military Security—Safeguarding Military Information*

17. Army Regulations, AR 380-10, *Military Security—Laws, Executive Orders, etc., Pertaining to Safeguarding Military Information.*

18. Navy Regulations, 1948, Chapter 15.

Section II. PERIODICALS

This section lists periodicals deemed pertinent to radiological defense engineers and to others.

1. *Nucleonics*, Monthly, McGraw-Hill Book Co., 3 years for $20.00. The leading magazine covering the technical aspect of nuclear physics: each month includes feature articles, new instruments, new books, reports of scientific meetings, and personnel items. The advertisements by manufacturers of radiological equipment are of considerable value.

2. *Ra-Det*, Monthly, Radiation Instruments Branch, Atomic Energy Commission. Contains information on radiation detection devices, feature articles on instrumentation, results of evaluation of commercially available radiation instruments, and specifications for new equipment.

3. *Radiology*, Monthly, Radiological Society of North America, Inc., 1 year for $8.00 Although intended primarily for physicians, roentgenologists, and others interested in the chemical aspects of X-ray and gamma radiations, it contains numerous feature articles on dosimetry, exposure safety, radiation effects on tissue, and so on. It is recommended for medical officers and health physicists. Contains abstracts of other literature.

4. *Physical Review*, Monthly, American Institute of Physics, 1 year for $15.00. The official publication of the American Physical Society, sent to its members. Advanced training in physics usually is required to understand the articles which cover many branches of physics. The great interest in nuclear physics is seen by the large number of reports in this and related subdivisions of physics.

Section III. TEXTBOOKS, COMMERCIALLY AVAILABLE

1. *Introduction to Atomic Physics*, by Otto Oldenberg, McGraw-Hill Co., 1949, $5.00. Intended for those who have taken general college physics and are familiar with the elements of chemistry. Stresses the relationship between theory and observed facts. An excellent text for the more advanced student.

2. *The Structure of Matter*, by F. O. Rice and E. Teller, John Wiley & Sons, 1949, $5.00. On a Junior and Senior College level for physics majors. Requires understanding of advanced mathematical functions. Descriptive treatment of atomic and nuclear phenomena based on wave mechanics.

3. *Electron and Nuclear Physics*, by J. Barton Hoag and S. A. Korff, D. Van Nostrand & Co., 1948, $5.00. Presents the results of modern physics on the college student level. Large section on nuclear physics. A unique feature at the end of each chapter is the inclusion of detailed directions for performing a number of laboratory experiments on the more important concepts of modern physics.

4. *Nuclear Radiation Physics*, by R. E. Lapp and H. L. Andrews, Prentice-Hall, Inc., 1948, $4.50. A relatively non-mathematical treatment of topics of interest to the radiological defense officers. Includes most of the topics in the lecture portion of the 6 weeks' Radiological Defense Course.

5. *Physics, Principles and Applications*, by Margenau, Watson, and Montgomery, McGraw-Hill Book Co., 1949, $5.00. A general textbook for sophomores majoring in engineering, mathematics, and physical sciences. Contains considerable basic material on modern physics. A good reference text in general college physics.

6. *Elements of Physics*, by Alpheus W. Smith, McGraw-Hill Book Co., 1948, $3.75. A general college textbook covering both the classical and modern aspects of physics at a somewhat less difficult level than text number 5.

7. *Radioactivity and Nuclear Physics*, by J. M. Cork, D. Van Nostrand Co., 1947, $4.00. A general text on radioactivity more advanced than text number 4. It presupposes a good knowledge of mathematics and physics at a level of the beginning graduate student in physics. Includes problems and answers.

8. *Explaining the Atom, by* Selig Hecht, Viking Press, 1947, $2.75. An interesting, light, non-mathematical narrative of the structure of the atom, atomic energy, and the atomic bomb for those with no special science background.

9. *Foundations of Modern Physics*, by Thomas B. Brown, John Wiley & Sons, 1949, $3.50. An excellent presentation of the most important concepts of modern physics with a minimum use of mathematics. Particularly good for officers with a limited knowledge of physics and mathematics who wish to extend their understanding of modern physics. However, a basic knowledge of physics is presupposed.

10. *The Science and Engineering of Nuclear Power*, by Clark Goodman, Addison-Wesley Press Inc., Cambridge, Mass. 1947, (2 vols.) $7.60 per volume. Material in these two volumes is based on a series of seminars given at M.I.T. on chain-reacting systems. Volume I is primarily a general survey of the fundamentals of chain-reacting systems. Volume II presents certain specific topics in detail. Valuable reference source for advanced students and nuclear physics engineers.

11. *Election and Nuclear Counters-Theory and Use,* by S. A. Korff, D. Van Nostrand Co., 1947, $3.00. Summarizes the pertinent facts regarding the theory of the discharge mechanism and the practical operations of ionization chambers, proportional counters, and Geiger-Mueller counter instruments. Intermediate level.

12. *An Introduction to Electronics,* by Ralph G. Hudson, MacMillan Co., 1949, $3.30. A non-mathematical presentation of the basic concepts of constitution of matter, electronic tubes, radio communications, television, and other applications of electronics. Some physics background is presupposed. Excellent for radiological defense officers who lack knowledge of electronics.

13. *Radioactive Measurements with Nuclear Emulsions,* by Herman Yagoda, John Wiley & Sons, 1949, $5.00. This book has been designed primarily as a guide on the use of emulsions in radioactive measurements. Sufficient theoretical material is included to understand the basic mechanisms involved. Of special value to those interested in the problems of radiological personnel exposure accounting systems, medical officers, and health physicists.

14. *Atomic Medicine,* by Capt. Charles F. Behrens (MC(USN)), Thomas Nelson and Sons, 1947, $7.50. Fills the need of bringing information on basic nuclear physics and physical chemistry, radiation biology and radiation therapy at an intermediate level between the layman and specialist between the covers of one book. An excellent reference book for the radiological defense officer.

15. *One World or None,* by N. Bohr (Foreward), McGraw-Hill Book Co., Inc., 1946, $1.00. A report to the public on the full meaning of the atomic bomb, given in a step-by-step analysis of the basic problems involved in the use of atomic energy, by outstanding scientists associated with the project, in collaboration with authorities in the political and military fields.

16. *Scientists Against Time,* by J. F. Baxter 3d, Little, Brown and Co., 1946, $5.00. Brief official history of the Office of Scientific Research and Development, a story of the development of weapons of war, and also of the advance in the complex field of human relations in a free world.

17. *The Problem of Reducing Vulnerability to Atomic Bombs,* by Ansley J. Coale, Princeton University Press, 1947, $2.50. Because most of the techniques required to study the practical methods by which mankind can substantially reduce its vulnerability to atomic warfare lie within the field of competence of the social sciences, this report of the Committee on Social and Economic Aspects of Atomic Energy is important.

18. *Matter, Energy and Radiation,* by J. R. Dunning and H. C. Paxton, McGraw-Hill Book Co., Inc., 1941 (3d impression) $3.50. Text originally prepared for students taking first semester of 2-year sequence in the sciences. This book, primarily in physics and certain aspects of astronomy, also is intended to serve as a principal reference text.

19. *Alsos,* by Samuel A. Goudsmit, Henry Schuman, Inc., 1947, $3.50. An account of the Alsos Mission, a scientific Intelligence Mission, whose purpose was to determine precisely the progress German scientists had made with the atomic bomb, and why they failed scientifically.

20. *Atomic Energy in War and Peace,* by G. G. Hamley, Reinhold Publishing Co., 1945, $1.87. Survey of the subject of radioactivity and nuclear fission with emphasis on the facts relating to the manufacture of U 235 and plutonium.

21. *Must We Hide?* by R. E. Lapp, Addison-Wesley Press, Inc., 1949, $3.17. The facts of atomic bombings as revealed by the Bikini tests, are reported in this book, and logical conclusions drawn from them are discussed.

22. *Nuclear Radiation Physics,* by R. E. Lapp and H. L. Andrews, Prentice-Hall, Inc., 1948, $4.50. An essentially non-mathematical approach to consistent discussion of radioactivity and nuclear structure is presented in this book which is the outgrowth of an elementary manual. Health Physics is included.

23. *Dawn Over Zero,* by William L. Laurence, Alfred A. Knopf, 1946, $3.00. The story of the first atomic bomb explosion at zero, the code name given to the spot in New Mexico chosen for the first atomic bomb test.

24. *General Physics,* by Robert Bruce Lindsay, John Wiley & Sons, Inc., 1940, $3.75. Basic introductory textbook for science students who have had higher mathematics and elementary, descriptive courses in physics.

25. *Atomic Structure,* by Leonard B. Lach, John Wiley & Sons, Inc., 1938, $4.50. In this book the

early concept of the electron, the positive ray, radioactivity, and X-rays are presented in an experimental and historical fashion. Special chapters are included for students desiring additional knowledge on nuclear structure.

26. *Nuclear Physics Tables,* by J. Mattauch, Inter-science Publishers, Inc., 1946, $10.20. Guide to study of original literature concerning nuclear physics.

27. *Atomic Artillery and the Atomic Bomb,* by John Kelloek Robertson, D. Van Nostrand Co., 1945, $2.50. A revision of the author's "Atomic Artillery," published in 1945. The purpose of this book is to explain, in language intelligible to a layman, the story of developments in one branch of modern physics.

28. *Introduction to Atomic Physics,* (Revised) by Henry Semat, Rinehart and Co., Inc., 1948, $4.00. Revised edition brings data on the nucleus up to date, but book still represents the content of a 1-semester course for students who have had 1 year of general college physics and calculus.

29. *Atomic Energy for Military Purposes,* by H. D. Smyth, Princeton University Press, 1947, $2.00. As a "report to the nation" the scientific and technical developments in the United States since 1939, culminating in the production of the atomic bomb, are given in this book.

30. *The "Particles" of Modern Physics,* by J. D. Stranathan, The Blakiston Company, 1942, $4.00. Many of the essential fundamental concepts of modern physics, and the experimental foundation for these concepts are emphasized in this book which is intended to serve also as a reference book for advanced students.

31. *Applied Nuclear Physics,* by Ernest Pollard, John Wiley & Sons, Inc., 1942, $3.00. While primarily a text to be read for description and explanation, the technical aspect of nuclear physics is emphasized in this book. It is especially useful in the fields of artificial radioactivity and transmutation.

32. *Atomic Energy in the Coming Era,* by David Dietz, Dodd, Mead and Company, 1945, $1.20. Problems of the atomic age discussed against the necessary background of information on which the reader may base his own conclusions.

33. *Outlines of Physical Chemistry,* by F. H. Getman and F. Daniels, John Wiley & Sons, Inc., 1943 (7 ed) $3.75. A technical presentation of general topics found in physical chemistry at the level of upper college level of chemistry or chemical engineering.

APPENDIX II

VISUAL TRAINING AIDS

The use of visual aids in short courses is especially to be encouraged. Where such aids are available, they should be used to enrich the course and add interest.

FILMS

MISC 1235 *THE ATOM STRIKES*
Running time: 31 minutes

This film shows effects of atomic bomb explosion on the cities of Hiroshima and Nagasaki. There is an interview between an unseen questioner and a Jesuit priest who witnessed the explosion at Hiroshima. He gives a vivid description of the explosion as seen from his monastery about 4 miles from zero point.

ANSM-74 *TALE OF TWO CITIES*
Running time: 11 minutes

A shorter version of MISC 1235. It shows the effects of the atomic bomb explosions on the cities of Hiroshima and Nagasaki in less detail. The effects are limited to those received by structures and areas. The film has been used during the teaching of Explosion Phenomena to show the direction and force of atomic blasts.

ANSM-86 *ATOMIC POWER*
Running time: 20 minutes

A March of Time film that shows the events leading to the first atomic bomb explosion. The people who were directly concerned with the project have reenacted the important events in the development of the bomb. The film is excellent for an orientation of atomic defense courses, but may have been seen by many people, as it was released some time ago to the general public.

EBF 370 *ATOMIC ENERGY*
Running time: 15 minutes

An especially good film to show in a few minutes, elementary atomic structure and energy release. Using animated drawings, the formation of helium from the hydrogen atoms, the relationship between solar energy and atomic energy and the loss or gain of atomic energy are shown.

MISC 1323 *OPERATION CROSSROADS*
Running time: 30 minutes

This is a color film of the two tests at Bikini. Some of the methods used in observing the effects of the blasts and in handling the radioactive planes and ships are shown. It includes excellent views of the explosions of both bombs—air and water bursts—and the effects of the blasts on the target arrays.

MN 6664 *PATHOLOGY*
Running time: 12 minutes

Shows effects of radiation on the various organs and tissues of the body. Material photographed is from the autopsies on animals exposed in the Test Able and Test Baker at Bikini. The language is on the technical side.

MISC 1396 *CROSSROADS—RADIOLOGICAL SAFETY*
Running time: 27 minutes

Shows the safety procedures followed at Operation Crossroads. Monitoring procedures, use of instruments, film badges, and health physics group in action are shown. Collecting samples for laboratory analysis is also shown.

INSIDE THE ATOM
Running time: 12 minutes

National Film

1270 Avenue of Americas
New York, New York

Released by the National Film Board of Canada, this is a documentary film showing the various phases of research work at the Chalk River Atomic Energy Plant in Ontario, Canada.

ATOMIC PHYSICS
Running time: 1 hr. 30 minutes

British film produced by J. Arthur Rank Organization using animation, historical reconstruction, living speakers, original apparatus, and scenes of modern research. It falls naturally into five parts which can be run as one film, or separately. Part I—The Atomic Theory; Part II—Rays from Atoms; Part III—The Nuclear Structure of the Atom; Part IV—Atom Smashing: The discovery of the neutron;

Part V—Uranium Fission: Atomic Energy. The film ends with a valuable recapitulation of what has been shown and a word about the future which promises so much if peace remains unbroken.

THE ELECTRON
Running time: 16 minutes

Explains the nature of electrons, types of electron flow, electromotive force, and magnetic fields.

REPORT ON THE ATOM
Running time: 25 minutes

The best available film on the future applications of atomic energy in a world at peace. The major emphasis is on the present program for harnessing the atom for research in industrial metallurgy, agriculture, and medicine. Many interior scenes in the various AEC laboratories are depicted, thus affording the public some much-needed impressions of the size and complexity of the Commission's research program. There is an important speech by Mr. Lillienthal on the dangers of over-enforcement of security, and the film ends on a hopeful note for the future of the atom's work for peace.

Coronet Films — *MATTER AND ENERGY*
207 East 37th Street — Running time: 20 minutes
New York, New York

Discusses constitution of matter, physical and chemical change, and atomic energy.

FILM STRIPS

Single Frame, 35 mm

	THE STORY OF THE
Visual Sciences	*ATOMIC BOMB*
Box 264	73 frames
Suffern, New York	Past price: $3.00

This is an excellently prepared series of 73 single frames, photographs, and diagrams and charts. It compares the steam, the electric, and the atomic power ages. It gives the description of the nuclear physics involved and also an historical background leading up to the discovery of fission. It shows in good visual style the various physical laws involved and also includes several shots of the atom smashers. The last nine frames have been taken from the famous *Smyth Report.* Highly recommended as a single, well-planned, coverage of the history, development, and subsequent utilization of atomic energy for both the bomb and power. Excellent for overall presentation in a single film strip.

McGraw-Hill Book Co. — *CHEMISTRY*
330 W. 42nd Street
New York 18, New York

Nine film strips on the study of chemistry constitute this series of visual training aids, four of which are pertinent to a technical, though elementary understanding of atomic energy and its uses. The level is out of senior high school chemistry or freshman college chemistry. The four filmstrips which may be purchased individually at $5.50 each, are—

Filmstrip 1—*The Kinetic Molecular Theory*—59 frames
Presents the laws of gases and shows the numerous applications and phenomena explained by these laws.

Filmstrip 2—*The Atomic Theory*—45 frames
Reviews the reasons that led to the development of the theory and its use in explaining many of the common basic laws of chemistry.

Filmstrip 5—*The Structure of the Atom*—49 frames
Develops the concept of atomic structure, gained from X-ray study, molecular crystal examination and bombarding atoms by means of "atom smashers." Identifies the electron, proton, neutron, and explains isotopes, ionization and chemical reactions.

Filmstrip 9—*The Periodic Table*—50 frames
Reviews earliest grouping of the chemical elements and develops the present periodic table. Shows the interrelationship among the elements in the various grouping.

LANTERN SLIDES

Keystone View Company — *ATOMS AND*
Meadville, Pa. — *ATOMIC ENERGY*

This series of standard 4″ × 5″ lantern slides consists of 5 units of 12 slides each, including an excellent teacher's manual with suggestions and test questions. A unit may be purchased separately at $7.20 per unit. The unit titles are—

Unit 1—*The Idea of the Atoms.*
Unit 2—*Atoms, Isotopes, and Radioactivity.*
Unit 3—*The Smashing of the Atom.*
Unit 4—*Atoms—From Mass Analysis to Mass Production.*
Unit 5—*Alamogordo to Bikini and Things to Come.*

An outstanding series of slides, well planned and clearly presented in pictorial form. The level is that of senior year high school or college freshman.

APPENDIX III

GLOSSARY OF COMMON RADIOLOGICAL TERMS

Absorption coefficient—Fractional decrease in intensity of a beam of radiation per unit thickness (linear absorption coefficient), per unit volume (mass absorption coefficient), or per atom (atomic absorption coefficient) of absorber.

Activation energy—The energy necessary to cause a particular reaction to begin. *Nuclear*: The amount of outside energy which must be added to a nucleus before a particular nuclear reaction will begin. *Chemical*: The amount of outside energy necessary to activate an atom or molecule so as to cause it to react chemically.

Alpha particle—A helium nucleus, consisting of two protons and two neutrons, with a double positive charge. Its mass is 4.002764 mu (mass units).

Alpha ray—Stream of fast-moving helium nuclei; a strongly ionizing and weakly penetrating radiation.

Amplification—As related to detection instruments, the process (either gas, electronic, or both) by which ionization effects are magnified to a degree suitable for their measurement.

Anode—Positive electrode; electrode to which negative ions are attracted.

Atom—Smallest particle of an element which is capable of entering into a chemical reaction.

Atomic number—Number of protons in the nucleus, hence the number of positive charges on the nucleus. Also the number of electrons outside the nucleus of a neutral atom. Symbol: Z.

Atomic weight—Relative weight of the atom of an element compared with the weight of one atom of oxygen taken at 16; hence, a multiple of $\frac{1}{16}$ the weight of an atom of oxygen.

Atomic Warfare—Warfare involving the employment of atomic weapons.

Atomic Weapon—A weapon, either explosive or nonexplosive, employing nuclear energy.

Avalanche—Process in which one electron produces a large number of additional free electrons by collision.

Avogadro's law—Hypothesis that equal volumes of all gases at the same pressure and temperature contain equal numbers of molecules. Hence, the number of molecules contained in 1 cm^3 of any gas under standard conditions is a universal constant.

Avogadro's number—Number of molecules in a gram-molecular weight of any substance (6.03×10^{23} molecules); also, the number of atoms in a gram-atomic weight of any element.

Background counting rate—Rate of radiation counting due to cosmic rays, to radioactive materials in the vicinity, and to a slight radioactive contamination of the materials of which the instrument is made.

Backscattering—Process of multiple scattering of radioactive particles from radioactive samples mounted on or near other matter. This results in additional particles entering a detector. Corrections for this effect may be made for each geometry factor used.

Beta particle—Charged particle emitted from the nucleus and having a mass and charge equal in magnitude to those of the electron.

Beta ray—A stream of beta particles, more penetrating but less ionizing than alpha rays; a stream of high-speed electrons.

Binding energy—The energy represented by the difference in mass between the sum of the component parts and the actual mass of the nucleus.

Calorie—Amount of heat necessary to raise the temperature of 1 gm of water 1°C. (from 14.5°C. to 15.5°C). Abrev: cal

Cathode—Negative electrode; electrode to which positive ions are attracted.

Cation—Positively charged ion.

Chain reaction—Any chemical or nuclear process in which some of the products of the process are instrumental in the continuation or magnification of the process.

Coincidence correction—Correction of the observed counting to indicate the true counting rate, made necessary because counters have an insensitive time. Sometimes called *coincidence loss correction.*

Conservation of mass-energy—Energy and mass are interchangeable in accordance with the equation $E = mc^2$, where E is energy, m is mass, and c is velocity of light.

Coulomb's law of electrostatic charges—The force of attraction or repulsion exerted between two electrostatic charges Q_1 and Q_2 a distance s apart separated by a medium of dielectric value E is given by the equation:

$$F = \frac{Q_1Q_2}{E\,s^2}$$

Counting rate-voltage characteristic—The counting rate of a radiation counter tube as a function of operating voltage for a given constant intensity of radiation.

Critical size—For a fissionable material, the minimum amount of a material which will support a chain reaction.

Cross section (nuclear)—Area subtended by an atom or molecule for the probability of a reaction.

Curie—Standard measure of rate of radioactivity decay; 3.7×10^{10} disintegrations/sec.

Dead time—Time interval, after recording a count, during which the counter tube and its circuit are completely insensitive and do not detect other ionizing events.

Decay—Disintegration of the nucleus of an unstable element by the spontaneous emission of charged particles and/or photons.

Decay time—See half-life.

Decay curve—Graph relating decay rate (counts per unit time) of a radioactive sample to time.

Densitometer—Instrument utilizing the photoelectric principle to determine the degree of opacity of developed photographic film.

Deuterium—A heavy isotope of hydrogen having one proton and one neutron in the nucleus. Symbol: D or $_1H^2$

Deuteron—Nucleus of a deuterium atom, containing one proton and one neutron.

Dosimeter—Instrument used to detect and measure an accumulated dosage of radiation.

Dyne—Unit of force, which, when acting upon a mass of 1 gm, will produce an acceleration of 1 cm/ sec^2.

Efficiency of a radiation counter tube—Probability that a count will take place when the radiation to be detected enters the effective volume of the counter tube.

Electrode—Either terminal of an electric source.

Electrometer—Electrostatic instrument for measuring the difference in potential between two points. Used to measure change of electric potential of charged electrodes resulting from ionization produced by radiation.

Electron—Negatively charged particle which is a constituent of every atom. Unit of negative electricity equal to 4.80×10^{-10} esu. Its mass is 0.000548 mu.

Electron volt—Amount of energy gained by an electron in passing through a potential difference of 1 volt. Abbrev: ev

Electroscope—Instrument for detecting the presence of electric charges by the divergence of charged bodies (usually gold leaves).

Electrostatic field—The region surrounding an electric charge in which another electric charge experiences a force.

Electrostatic unit of charge (statcoulomb)—That quantity of electric charge which, when placed in a vacuum 1 cm distant from an equal and like charge, will repel it with a force of 1 dyne.

Element—Pure substance consisting of atoms of the same atomic number, which cannot be subdivided by ordinary chemical change.

Endoergic reaction—Reaction which absorbs energy.

Energy—Capacity for doing work. Potential energy is the energy inherent in a mass because of its position with reference to other masses. Kinetic energy is the energy possessed by a mass because of its motion; cgs units: gm–cm^2/sec^2 or erg

Erg—Unit of work done by a force of 1 dyne acting through a distance of 1 cm. Unit of energy which can exert a force of 1 dyne through a distance of 1 cm; cgs units: dyne–cm or gm–cm^2/sec^2

Exoergic reaction—Reaction which liberates energy.

Film badge—Small piece of X-ray or similar photographic film enclosed in a lightproof paper usually crossed by lead or cadmium strips, carried by a person, in a small metal or plastic frame. The badge is used to determine the amount of radiation to which an individual is exposed.

Fission—See *Nuclear fission.*

Fission products—Elements and/or particles produced by fission.

Force—The push or pull which tends to impart motion to a body at rest, or to increase or diminish the speed or change the direction of a body already in motion.

Fusion—See *nuclear fusion.*

Gamma ray—High-frequency electromagnetic radiation with a range of wave length from 10^{-8} to 10^{-11} cm, emitted from the nucleus.

Gas amplification—Ration of the charge collected to the charge produced by the initial ionizing event.

Geiger-Mueller (G-M) counter—Highly sensitive gas filled radiation-measuring device which operates at voltages above the Geiger threshold and below voltages at which complete gaseous break-down would occur.

Geiger region—Voltage interval in which the charge transferred per isolated count is independent of the charge produced by the initial ionizing event.

Geiger threshold—Lowest voltage at which all pulses produced by an ionizing event are the same size regardless of the energy of the initial ionizing radiation.

Geometry factor—The fraction of the total solid angle about the source of radiation that is subtended by the detector.

Graham's law—The relative rates of diffusion of gases under the same conditions are inversely proportional to the square roots of the densities of the gases.

Gravitation—Universal force of attraction existing between all material bodies.

Half-life—Time required for a radioactive substance to lose 50 percent of its activity by decay.

Half thickness—Thickness of absorbing material necessary to reduce the intensity of radiation by one-half.

Heavy water—Popular name for water which is composed of two atoms of deuterium and one atom of oxygen.

Hydro atom—The atom of lightest mass and simplest atomic and nuclear structure, consisting of one proton with one orbital electron. Its mass is 1.008123 mu.

Induced Radioactivity—Artificial radioactivity which may be produced in certain elements as the result of the capture of neutrons by these elements.

Initial ionizing event—Ionizing event which initiates a count.

Integrating circuit—Electronic circuit which records, at any time, an average value for the number of events occurring per unit time; or an electrical circuit which records total number of ions collected in a given time.

Intensity of radiation—Amount of radiant energy emitted in a specified direction per unit time and per unit surface area.

Ion—Atomic particle, atom, or chemical radical (group of chemically combined atoms) bearing an electrical charge, either positive or negative, caused by an excess or deficiency of electrons.

Ion chamber—Container of gas in which an electric field exists because of a system of charged electrodes.

Ionization—Act or result of any process by which a neutral atom or molecule acquires either a positive or a negative charge.

Ionization potential—The potential necessary to separate one electron from an atom with the formation of an ion with one elementary charge.

Ionizing event—Event in which an ion is produced.

Isobars—Elements having the same mass number but different atomic numbers.

Isotope—One of two or more forms of an element having the same atomic number (nuclear charge) and hence occupying the same position in the periodic table. All isotopes are identical in chemical behavior, but are distinguishable by small differences in atomic weight. The nuclei of all isotopes of a given element have the same number of protons but differ in the number of neutrons.

Magnetic field—The region surrounding a magnetic pole in which another magnetic pole experiences a force.

Mass—Quantity of matter.

Mass number—The number of nucleons in the nucleus of an atom.
Symbol: A

Mass unit—Unit of mass based upon $\frac{1}{16}$ the weight of an oxygen atom ($_8O^{16}$) taken as 16.00000. Abbrev: mu

Mean free path of a molecule—Average distance which a molecule moves between collisions. Abbrev: MFP

Meson—Short-lived particle carrying a positive or negative charge or no charge and having a variable mass in multiples of the mass of the electron. Also called mesotron.

Mesotron—See *meson*.

Metastable state—An excited state of a nucleus which returns to the ground state by the emission of a gamma ray over a *measurable half-life*.

Mev—Abbreviation for million electron volts. See *electron volt*.

Molecule—Ultimate unit quantity of a compound which can exist by itself and retain all the properties of the original substance.

Molecular weight—Sum of the atomic weights of all the atoms in a molecule.

Monitoring, radiological—Determination of the existence and the intensity of radiation present in a given object or area.

Neutron—Elementary nuclear particle with a mass approximately the same as that of a hydrogen atom and electrically neutral; a constituent of the atomic nucleus. Its mass is 1.00893 mu.

Newton's laws of motion—1. Every body continues in its state of rest or of uniform motion in a straight line except insofar as it may be compelled to change that state by the action of some outside force. 2. An unbalanced force acting upon a body causes the body to accelerate in the direction in which the force is applied, and the acceleration is directly proportional to the magnitude of the unbalanced force and inversely proportional to the mass of the body. 3. For every action there is an equal and opposite reaction.

Nonself-quenching counter tube—Counter tube which requires the use of a quenching circuit to terminate the discharge.

Normalized plateau slope—Slope of the substantially straight portion of the counting rate-voltage characteristic expressed as a ratio of the percentage change in counting rate near the midpoint of the plateau to the percentage change in operating voltage.

Nuclear fission—A special type of nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.

Nuclear fusion—Act of coalescing two or more nuclei.

Nucleon—Common name for the constituent parts of the nucleus. At present applied to protons and neutrons, but will include any other particle found to exist in the nucleus.

Nucleon number—The number of nucleons in the nucleus of an atom. Identical with the mass number of A number.

Nucleus—Heavy central part of an atom in which most of the mass and the total positive electric charge are concentrated. The charge of the nucleus, an integral multiple (Z) of the charge of the proton, is the essential factor which distinguishes one element from another. Z is the atomic number.

Nuclide—A general term referring to all nuclear species—both stable (about 270) and unstable (about 500—of the chemical elements as distinguished from the two or more nuclear species of a single chemical element which are called isotopes.

Operating voltage—Voltage across a radiation counter tube in the quiescent state.

Packing fraction—Difference between the atomic weight in mass units and the mass number of an element divided by the mass number and multiplied by 10,000. It indicates nuclear stability. The smaller packing fraction, the more stable the element.

Photoelectric effect—The process by which a photon ejects an electron from its atom. All the energy of the photon is absorbed in ejecting the electron and in imparting kinetic energy to it.

Photo dosimetry—Determination of the accumulative dosage of radiation by use of photographic film.

Photon—A quantity of energy emitted in the form of electromagnetic radiation whose value is the product of its frequency and Planck's constant. The equation is: $E = hv$

Planck's constant—A natural constant of proportionality h relating the frequency of a quantum of energy to the total energy of the quantum;

$$h = \frac{E}{V} = 6.6 \times 10^{-27} \text{ erg-sec}$$

Plateau—Approximately horizontal portion of the counting rate-voltage characteristic of a radiation counter tube. Voltage range throughout which any ionizing event, regardless of type or energy, will give the same size pulse.

Positron—Nuclear particle equal in mass to the electron and having an equal but opposite charge. Its mass is 0.000548 mu.

Potential difference—Difference in potential between any two points in a circuit; work required to carry a unit positive charge from one point to another.

Power—Time rate of doing work; time rate of expenditure of energy; cgs unit: $gm\text{-}cm^2/sec^3$

Pressure—Perpendicular component of force applied to a unit area; total force divided by total area; cgs unit: $dyne/cm^2$

Primary electron—The electron ejected from an atom by an initial ionizing event, as caused by a photon or beta particle.

Proportional counter—Gas-filled radiation detection tube in which the pulse produced is proportional to the number of ions formed in the gas by the primary ionizing particle.

Proportional region—Voltage range in which the gas amplification is greater than one and in which the charge collected is proportional to the charge produced by the initial ionizing event.

Proton—Nuclear particle with a positive electric charge equal numerically to the charge of the electron and a mass of 1.007575 mu.

Quantum—A discrete quantity of energy equal to the product of its frequency and Planck's constant. The equation is: $E = hv$

Quantum level—An energy level of an electron, distinct from any other of its energy levels by discrete quantities dependent upon Planck's constant.

Quantum number—One of a set of integral or half-integral numbers, one for each degree of freedom. which determine the state of an atomic system in terms of constants of nature.

Quantum state—See *quantum level*.

Quantum theory—Concept that energy is radiated intermittently in units of definite magnitude called *quanta*.

Quenching—Process of terminating the discharge in a counter tube.

Quenching circuit—Circuit which causes the discharge to cease.

Quenching vapor—Polyatomic gas used in Geiger-Mueller counters to quench or extinguish a pulse, thus eliminating the need for an external quenching resistor of an electronic circuit. The quenching action of vapor results from its absorption of ultraviolet photons emitted by excited atoms and prevents emission of secondary electrons when ions reach the cathode.

Radiation—1. Any electromagnetic wave (quantum). 2. Any moving electron or nuclear particle, charged or uncharged, emitted by a radioactive substance.

Radioactivity—Process whereby certain atoms undergo spontaneous atomic disintegration in which energy is liberated, generally resulting in the formation of new nuclides. The process is accompanied by the emission of one or more types of radiation, such as alpha particles, beta particles, and gamma radiation.

Radiological Defense—Protective measures to minimize personnel and material damage from radioactivity. This definition is interpreted to include measures such as: Training, organization, and distribution of personnel; development, provision, and maintenance of fixed and portable structures and equipment; use of detecting equipment; protection or removal of exposed personnel, and decontamination of personnel, equipment, structures, or terrain.

Radiological monitoring—See *monitoring, radiological*.

Radiological Warfare—Radiological warfare is described as the offensive and defensive use of radioactivity in warfare. The offensive phase includes the use of radioactive materials and atomic bombs when used primarily for their radioactive effect. It also includes the secondary radioactive effect of atomic bombs used primarily as blast or incendiary weapons. The defensive phase of radiological warfare encompasses the field of Radiological Defense.

Radiological Weapon—An atomic weapon in which radioactive substances are employed primarily to create hazards by utilizing radiation to injure enemy personnel or to contaminate material.

Rate meter—See *integrating circuit*.

Reaction—Any process involving a chemical or nuclear change.

Recovery time—Time interval, after a count recording, before the pulses produced by the next ionizing event in the counter are of substantially full size.

Relative plateau slope—The relative increase in the number of counts as a function of voltage expressed in percentage per 100 volts increase above the Geiger threshold.

Resistance—The opposition offered by a conductor to the passage of electric current through it. Property of a conductor, depending on its dimensions, material, and temperature, which determines the magnitude of the current produced by a given difference in potential. The practical unit of resistance is the *ohm*.

Resolving time—Minimum time interval between counts which can be detected. It may refer to an electronic circuit, a mechanical recording device, or a counter tube.

Roentgen—quantity of X or γ radiation which produces 1 esu of positive or negative electricity/cm^3 of air at standard temperature and pressure or 2.083×10^9 ion pairs/cm^3 of dry air.

Rutherford—Unit of radioactive disintegration rate equal to one million (10^6) disintegrations per second. Abbrev: rd

Secondary electron—An electron ejected from an atom by the primary electron or by another secondary electron already ejected.

Self-absorption—Absorption of radiation by the source material itself.

Self-quenching counter tube—Counter tube in which the discharge is terminated by an internal mechanism with the tube.

Spurious count—Count caused by an agency other than the radiation which it is desired to detect.

Statcoulomb—See electrostatic unit of charge.

Unfissioned Material—Fissionable material which has not undergone fission. In the instance of an atomic bomb explosion, unfissioned material consists of that portion of the original bomb material which did not enter into the nuclear reaction. Unfissioned material is an alpha particle emitter.

Voltage pulse—Change in the voltage of the central electrode system of a counter tube.

Work—The transfer of energy by the application of a force through a distance. Product of a force and the distance through which it moves; cgs unit: gm–cm^2/sec^2

Yield, fission—The percentage of a given isotope formed in a fission reaction.

APPENDIX IV
MISCELLANEOUS TABLES AND GRAPHS

Table VII.

TABLE OF SOME COMMON RADIOLOGICAL QUANTITIES AND CONSTANTS

Angstrom unit	$\mathring{A} = 10^{-8}$ cm
	$= 10^{-4}$ micron
Avogadro's number	$N_o = 6.025 \times 10^{23}$ molecules/gm-mole
British thermal unit	Btu = 252 cal
	= 778 ft-lb
	= 1,055 joules
	$= 2.93 \times 10^{-4}$ kw-hr
Calorie	cal = 0.00397 Btu
	= 4.2 joules
	$= 1.16 \times 10^{-6}$ kw-hr
Centimeter	$cm = 10^{8}\ \mathring{A}$
	= 0.3937 in.
	$= 10^{4}$ microns
Curie	$= 3.7 \times 10^{10}$ disintegrations/sec
Electron, charge	$e = 4.80 \times 10^{-10}$ statcoulomb or esu
	$= 1.60 \times 10^{-20}$ abcoulomb or emu
	$= 1.60 \times 10^{-19}$ coulomb
Electron, volt	$ev = 1.6 \times 10^{-12}$ erg
	$= 1.6 \times 10^{-19}$ joule
Energy equivalent of mass of unit atomic weight	= 931 Mev
Erg	$= 7.37 \times 10^{-8}$ ft-lb
	$= 10^{-7}$ joule
Gram	$gm = 6.24 \times 10^{5}$ Mev

Horsepower	$hp = 6.03 \times 10^{22}$ mu
	$= 550$ ft-lb/sec
	$= 746$ watts
Joule	$= 9.48 \times 10^{-4}$ Btu
	$= 0.239$ cal
	$= 10^{7}$ ergs
	$= 6.25 \times 10^{18}$ ev
	$= 2.78 \times 10^{-7}$ kw-hr
Mass of	
alpha particle	$m = 6.598 \times 10^{-24}$ gm
electron (rest mass)	$m_e = 9.107 \times 10^{-28}$ gm
H^1 atom	$m_{H^1} = 1.673 \times 10^{-24}$ gm
neutron	$m_n = 1.675 \times 10^{-24}$ gm
proton	$m_p = 1.673 \times 10^{-24}$ gm
Mass unit	$mu = 1.660 \times 10^{-24}$ gm
	$= 931$ Mev
	$= 1.49 \times 10^{-3}$ erg
Planck's constant	$h = 6.624 \times 10^{-27}$ erg-sec
Roentgen	$r = 1$ statcoulomb/cm^3 (air)
	$= 2.083 \times 10^{9}$ ion pairs/cm^3 (air)
	$= 1.61 \times 10^{12}$ ion pairs/gm (air)
	$= 6.77 \times 10^{4}$ Mev/cm^3 (air)
	$= 5.24 \times 10^{7}$ Mev/gm (air)
	$= 83.8$ ergs/gm (air)
Rutherford	$rd = 10^{6}$ disintegrations/sec
Velocity of light in vacuum	$c = 3 \times 10^{10}$ cm/sec

Table VIII.

TABLE OF MASS-ENERGY CONVERSIONS

Multiply—	by—	to obtain—
Mass units (mu)	9.31×10^{2}	Mev
	1.49×10^{-3}	ergs
	3.56×10^{-11}	calories
	4.15×10^{-17}	kilowatt-hours
Mev	1.07×10^{-3}	mass units
	1.60×10^{-6}	ergs
	3.83×10^{-14}	calories
	4.45×10^{-20}	kilowatt-hours
Ergs	6.71×10^{2}	mass units
	6.24×10^{5}	Mev
	2.39×10^{-8}	calories
	2.78×10^{-14}	kilowatt-hours
Calories (cal)	2.81×10^{10}	mass units
	2.62×10^{13}	Mev
	4.18×10^{7}	ergs
	1.16×10^{-6}	kilowatt-hours
Kilowatt-hours (kw-hr)	2.41×10^{16}	mass units
	2.25×10^{19}	Mev
	3.60×10^{13}	ergs
	8.60×10^{5}	calories

Table IX. Electromagnetic Spectrum

	Frequency (cycles/sec)	Wave Length	Energy of Photon	
			electron volts	ergs
Cosmic	10^{23}	3×10^{-5} Å	4.1×10^{8}	6.6×10^{-4}
	10^{22}	3×10^{-4} Å	4.1×10^{7}	6.6×10^{-5}
Gamma	10^{21}	3×10^{-3} Å	4.1×10^{6}	6.6×10^{-6}
	10^{20}	3×10^{-2} Å	4.1×10^{5}	6.6×10^{-7}
	10^{19}	0.3Å	4.1×10^{4}	6.6×10^{-8}
X	10^{18}	3Å	4.1×10^{3}	6.6×10^{-9}
	10^{17}	30Å	4.1×10^{2}	6.6×10^{-10}
Ultraviolet	10^{16}	300Å	4.1×10	6.6×10^{-11}
	10^{15}	3×10^{3} Å	4.1	6.6×10^{-12}
Visible	10^{14}	3×10^{4} Å	0.41	6.6×10^{-13}
Infrared	10^{13}	30μ	4.1×10^{-2}	6.6×10^{-14}
	10^{12}	300μ	4.1×10^{-3}	6.6×10^{-15}
	10^{11}	3 mm	4.1×10^{-4}	6.6×10^{-16}
	10^{10}	3 cm	4.1×10^{-5}	6.6×10^{-17}
	10^{9}	30 cm	4.1×10^{-6}	6.6×10^{-18}
Radio	10^{8}	3 m	4.1×10^{-7}	6.6×10^{-19}
	10^{7}	30 m	4.1×10^{-8}	6.6×10^{-20}
	10^{6}	300 m	4.1×10^{-9}	6.6×10^{-21}
	10^{5}	3 km	4.1×10^{-10}	6.6×10^{-22}
	10^{4}	30 km	4.1×10^{-11}	6.6×10^{-23}
Electric	10^{3}	300 km	4.1×10^{-12}	6.6×10^{-24}

Table X.

ATOMIC MASSES IN MASS UNITS
Physical Scale

Z No.	Element	A No.	Mass (mu)	Z No.	Element	A No.	Mass (mu)
-1	Electron	0	0.000548	9	Fluorine	16	16.0175**
0	Neutron	1	1.00893			17	17.0075
1	Proton	1	1.007575			18	18.0065
1	Hydrogen	1	1.008123*			19	19.00450*
		2	2.014708*			20	20.0067
		3	3.01702			21	21.0059**
1	Deuteron	2	2.014174	10	Neon	18	18.0114**
2	Alpha	4	4.002764			19	19.00781
2	Helium	3	3.01700*			20	19.99877*
		4	4.00390*			21	20.99963*
		5	5.0137			22	21.99844*
		6	6.0209			23	23.0018**
3	Lithium	5	5.0136**	11	Sodium	21	21.0035**
		6	6.01697*			22	21.9999
		7	7.01822*			23	22.99618*
		8	8.02502			24	23.9975
4	Beryllium	6	6.0219			25	24.9967**
		7	7.01916	12	Magnesium	22	22.0062**
		8	8.00785			23	23.0002
		9	9.01503*			24	23.9924*
		10	10.01677			25	24.9938*
		11	11.0277**			26	25.9898*
5	Boron	9	9.01620			27	26.9928
		10	10.01618*	13	Aluminum	25	24.9981
		11	11.01284*			26	25.9929
		12	12.0190			27	26.9899*
		13	13.0207**			28	27.9903
6	Carbon	10	10.02100			29	28.9893
		11	11.01495			30	29.9954**
		12	12.00382*	14	Silicon	27	26.9949
		13	13.00751*			28	27.9866*
		14	14.00767			29	28.9866*
		15	15.0165**			30	29.9832*
7	Nitrogen	12	12.0233**			31	30.9862
		13	13.00988			32	31.9849**
		14	14.00751*	15	Phosphorus	29	28.9919**
		15	15.00489*			30	29.9873
		16	16.00668			31	30.9843*
		17	17.014**			32	31.9827
8	Oxygen	14	14.0131**			33	32.9826**
		15	15.0078	16	Sulfur	31	30.9899**
		16	16.000000*			32	31.98089*
		17	17.00450*			33	32.9800*
		18	18.00490*			34	33.97710*
		19	19.0139*			35	34.9788

Table X—Continued

Z No.	Element	A No.	Mass (mu)	Z No.	Element	A No.	Mass (mu)
16	Sulfur	36	35.978*	30	Zinc	64	63.954*
17	Chlorine	33	32.9860**			65	64.95654
		34	33.9801			66	65.954*
		35	34.97867*			67	66.954*
		36	35.9788			68	67.955*
		37	36.97750*			70	69.954*
		38	37.981	31	Gallium	69	68.952*
		39	38.9794**			71	70.952*
18	Argon	35	34.9850**	32	Germanium	74	
		36	35.9780*			76	
		37	36.9777**	33	Arsenic	75	74.934*
		38	37.974*	34	Selenium	78	77.938*
		39	38.9755**			80	79.942*
		40	39.9756*	35	Bromine	79	78.929*
		41	40.9770			81	80.930*
19	Potassium	37	36.9830**	36	Krypton	78	77.945*
		38	37.9795**			82	81.939*
		39	38.9747*			84	83.938*
		40	39.9760*			86	85.939*
		41	40.9739*	37	Rubidium	85	
20	Calcium	40	39.9753*	38	Strontium	84	
		42	41.9711*			86	
		43	42.9723*			87	
		45	44.968			88	
21	Scandium	45	44.9669*	39	Yttrium	89	
		46	45.96909**	40	Zirconium	90	
22	Titanium	46	45.9661*			91	
		47	46.9647*			92	
		48	47.9631*			94	
		49	48.9646*			96	
		50	49.9621*	41	Columbium	93	92.926*
		51	50.9587	42	Molybdenum	94	93.945*
23	Vanadium	51	50.9577*			95	94.946*
		52	51.95857**			96	95.944*
24	Chromium	51	50.958			97	96.945*
		52	51.956*			98	97.943*
		53	52.956*			100	99.945*
		54	53.960*	43	Technetium		
25	Manganese	55	54.957*	44	Ruthenium	96	95.945*
26	Iron	54	53.957*			98	97.943
		56	55.9568*			99	98.944*
		57	56.957*			100	99.942
27	Cobalt	59	58.94*			101	100.946
28	Nickel	58	57.9594*			102	101.941
		60	59.9495*	45	Rhodium	103	102.941
		61	60.9537*	46	Palladium	102	101.941*
		62	61.9493*			104	103.941*
		64	63.9471			105	104.942*
29	Copper	63	62.957*			106	105.941*
		64	63.955			108	107.941*
		65	64.955			110	109.941*

Table X—Continued

Z No.	Element	A No.	Mass (mu)
47	Silver	107	106.945*
		108	107.947
		109	108.944*
48	Cadmium	106	
		108	
		110	
		111	
		112	
		113	
		114	
		116	
49	Indium	113	
		115	
50	Tin	115	114.940*
		116	115.939*
		117	116.937*
		118	117.937*
		119	118.938*
		120	119.937*
		122	121.945*
		124	123.944*
51	Antimony	121	
		123	
52	Tellurium	126	125.937*
		128	127.936*
53	Iodine	127	126.933*
54	Xenon	129	128.946*
		132	131.946*
55	Cesium		
56	Barium	138	137.916*
57	Lanthanum	139	138.953*
58	Cerium	136	
		138	
		140	
		142	
59	Praseodymium	141	
60	Neodymium	145	144.962*
		146	145.962*
		148	147.962*
		150	149.964*
61	Prometheum	147	
62	Samarium	144	
		147	
		149	
		150	
		152	
		154	
63	Europium	151	
		153	
64	Gadolinium	154	153.971*
		155	154.971*
		156	155.972*
		157	156.973*
		158	157.973*
		160	159.974*
65	Terbium	159	
66	Dysprosium	158	
		160	
		161	
		162	
		163	
		164	
67	Holmium	165	164.98*
68	Erbium	162	
		164	
		166	
		167	
		168	
		170	
69	Thulium	169	
70	Ytterbium	168	
		170	
		171	
		172	
		173	
		174	
		176	
71	Lutecium	175	
72	Hafnium	174	
		176	
		177	
		178	
		179	
		180	
73	Tantalum	181	180.928*
74	Tungsten	184	184.00*
75	Rhenium	187	186.981*
76	Osmium	189	189.04*
		190	190.030*
		192	192.04*
77	Iridium	191	191.040*
		193	193.040*
78	Platinum	194	194.039*
		195	195.039*
		196	196.039*
		198	198.050*
79	Gold	197	197.039*
80	Mercury	200	200.028*

Table X—Continued

Z No.	Element	A No.	Mass (mu)	Z No.	Element	A No.	Mass (mu)
81	Thallium	203	203.050*	91	Protoactinium	231	
		205	205.050	92	Uranium	235	235.1133*
82	Lead	204	204.050*			238	238.1204*
		206	206.050*	93	Neptunium	234	234.1119**
		207	207.050*			235	235.1137**
		208	208.050*			236	236.1158**
83	Bismuth	209	209.050*			237	237.1176**
84	Polonium	210				238	238.1199**
85	Astatine	211				239	239.1222**
86	Radon	222		94	Plutonium	238	238.1197**
87	Francium	223				239	239.1228**
88	Radium	226	226.10*	95	Americium	241	241.1269**
89	Actinium	227		96	Curium	240	240.1259**
90	Thorium	232	232.12*			242	242.1293**
		234	234.1121				

* Mass of isotope which exists in nature.
** Mass calculated by means of atomic mass equation—not observed.

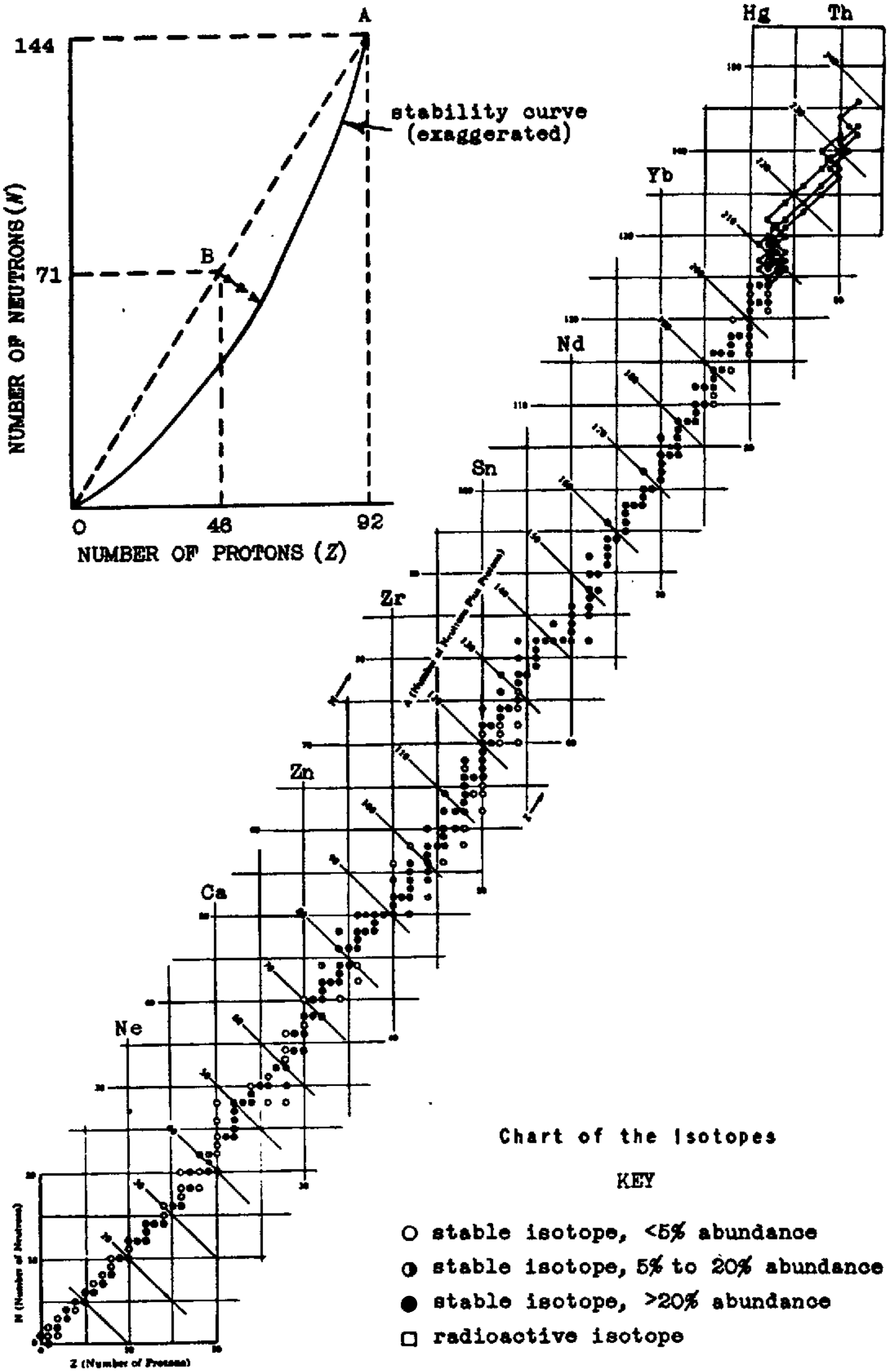
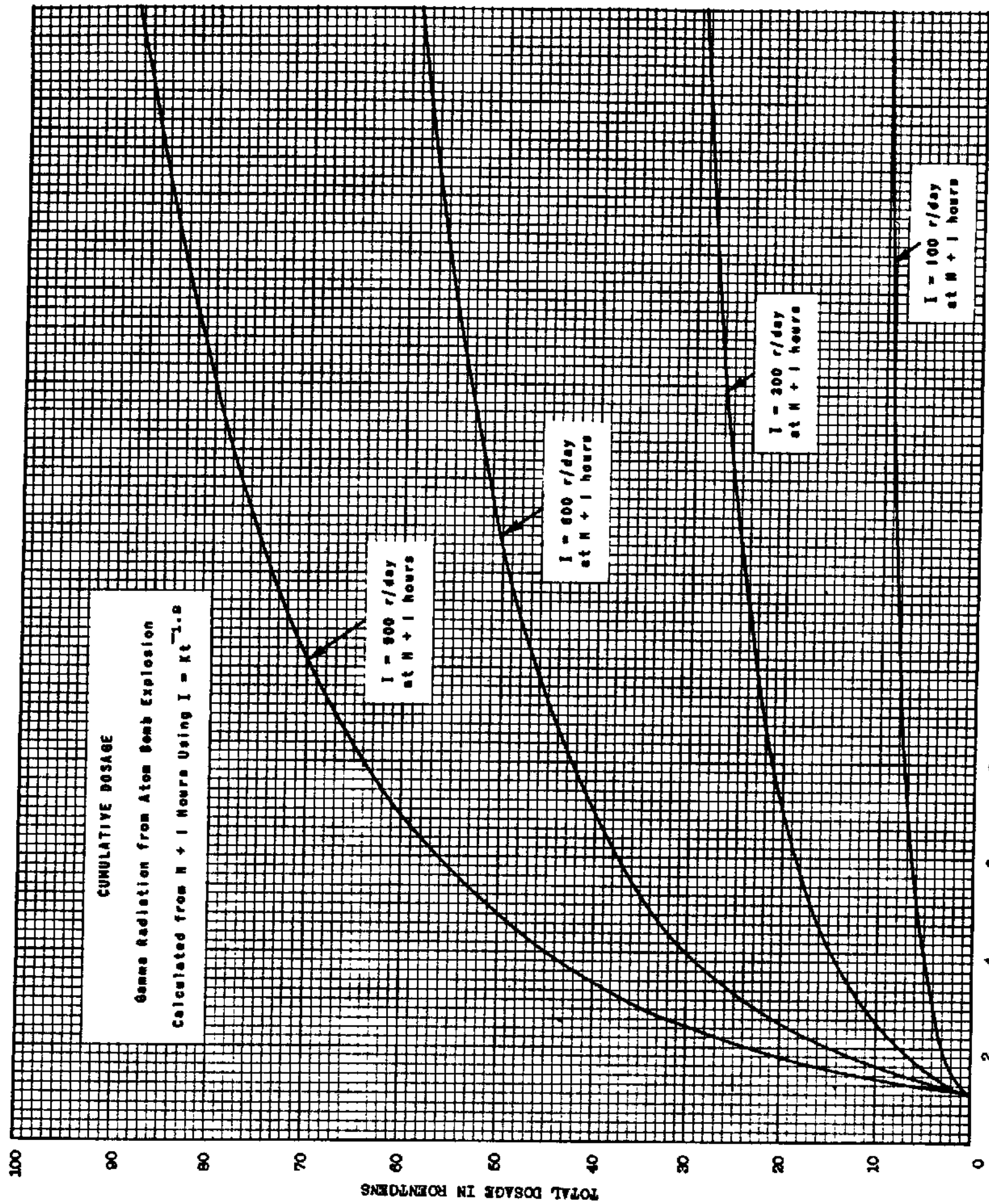


Figure 42. Neutron proton ratio.


CUMULATIVE DOSAGE
Gamma Radiation from Atom Bomb Explosion
Calculated from H + 1 Hours Using I = Kt$^{-1.2}$
I = 900 r/day at H + 1 hours
I = 600 r/day at H + 1 hours
I = 300 r/day at H + 1 hours
I = 100 r/day at H + 1 hours
TOTAL DOSAGE IN ROENTGENS
0
10
20
30
40
50
60
70
80
90
100
TIME IN HOURS
2
4
6
8
10
12
14
16
18
20
22
24
Figure 43.

TIME IN HOURS
Figure 43.

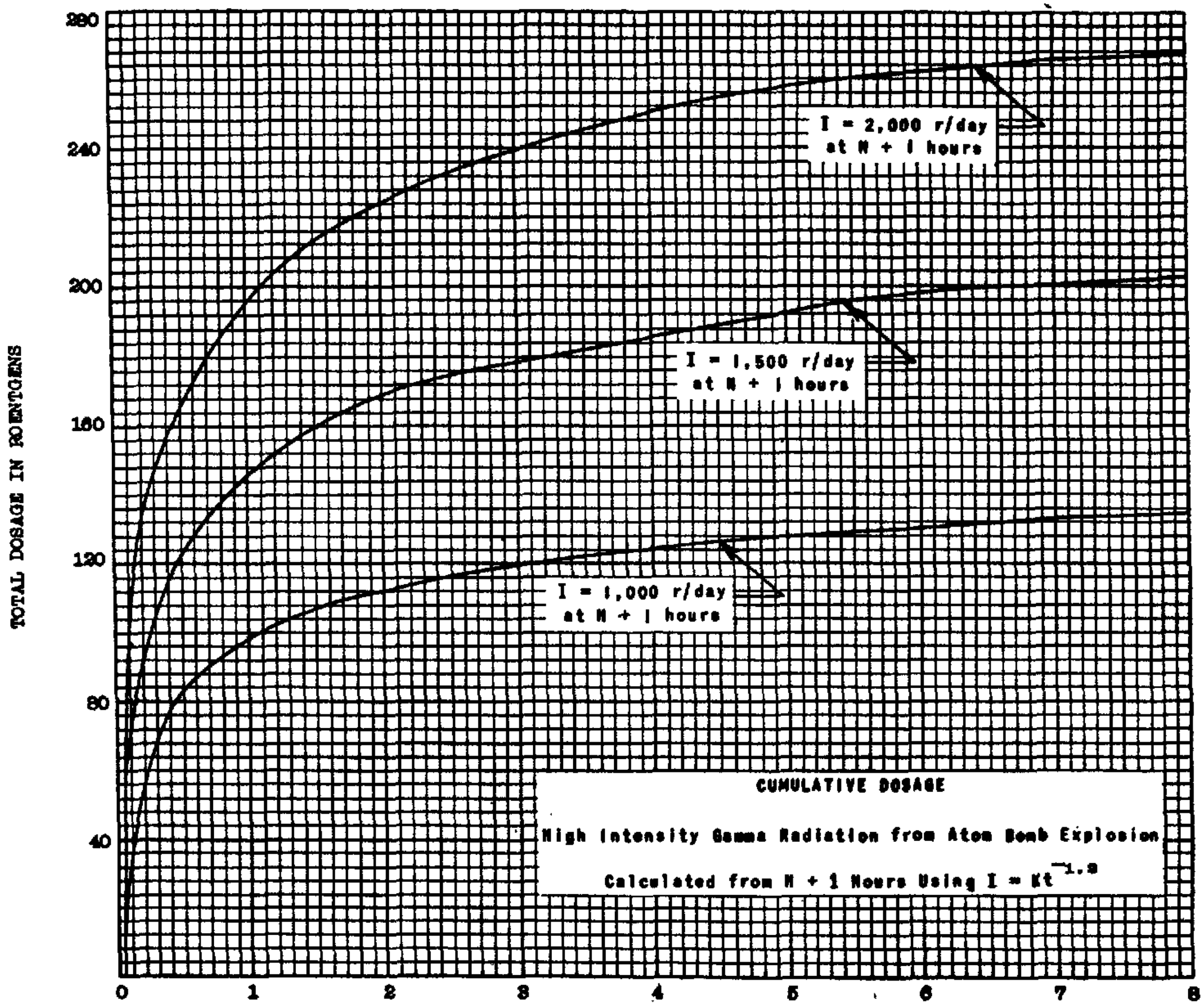


Figure 44.

The graph, figure 45, gives an interesting relationship between energy of charged particles and their penetrating or range in aluminum and air. The penetrating power of any charged particle is dependent upon the size of the particle, the substance it is moving in, and the initial energy of the particle. For example, it can be seen from the graphs that for the same initial energy the alpha particles penetrate the least, while the beta particles, very much smaller than the alphas, penetrate the most in aluminum. The range of deuterons and protons lies in between, since their size is intermediate between the alphas and betas. The greater the initial energy of the particle the greater the penetration. Generally, the denser the material, the less the penetration.

It may be expected that a material which reduces the range of these radiations, in effect, serves as a shield against the radiation; hence, the interest which the radiological defense officer has in the stopping power or absorption coefficient of various substances. Figure 46 shows the absorption of gamma rays of different initial energy by lead. Especially important is the "total effect" curve.

A rather easy method to determine the shielding thickness of several common substances to gamma rays when the activity, and working time are given, is possible by the use of table XI.

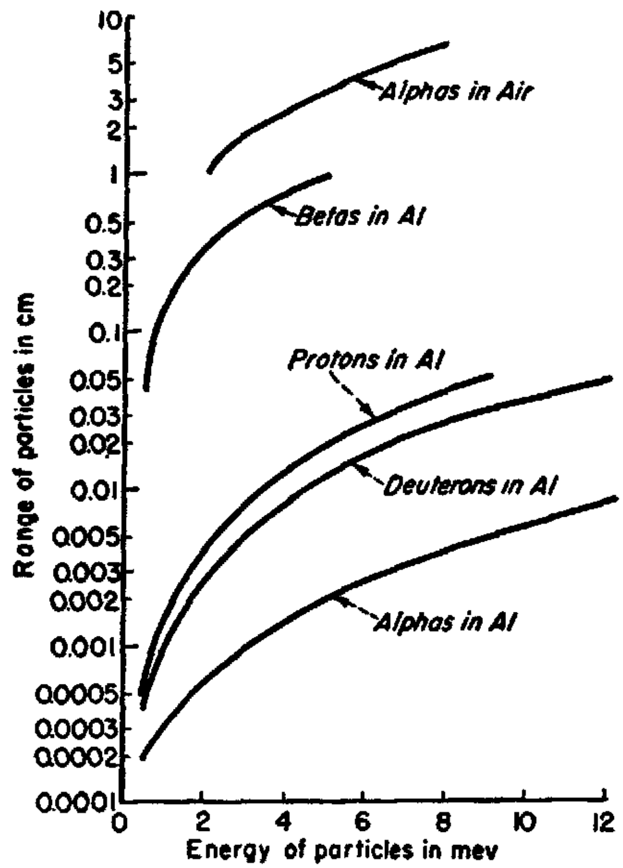


Figure 45. Interaction of charged particles with matter.

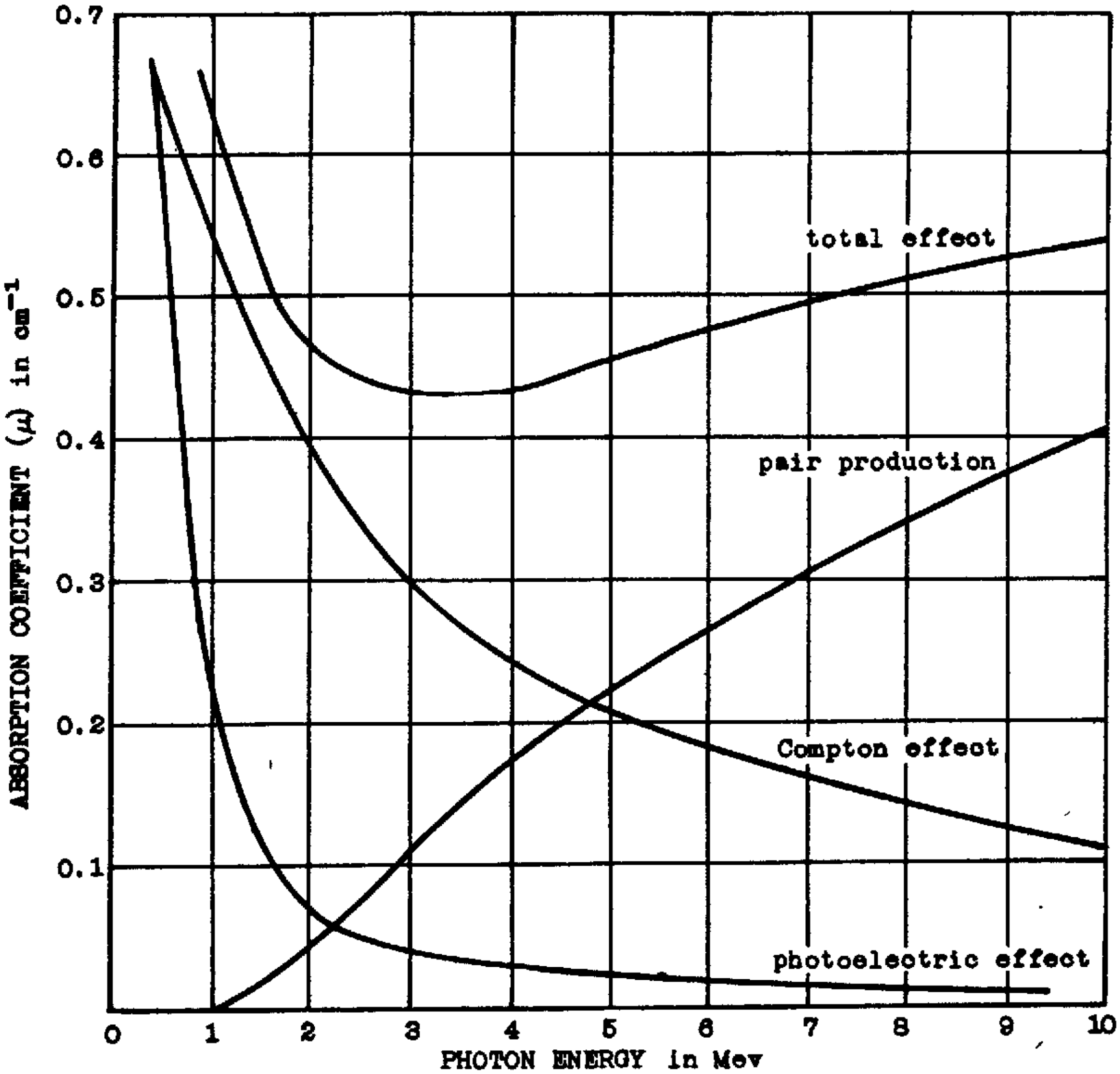


Figure 46. Absorption of gamma radiation in lead.

Table XI. Gamma-Ray Shielding Data

Activity	Energy (Mev) 0.2	0.5	0.8	1	1.5	2.0	2.5	3.0	6.0
10 mc	− .50	− .86	−1.02	− 1.05	− .83	− .61	− .39	− .13	− .23
20 mc	− .36	− .44	− .33	− .14	+ .33	+ .76	+ 1.06	+ 1.36	+ 1.68
50 mc	− .17	+ .09	+ .59	+ 1.04	+ 1.82	+ 2.55	+ 2.95	+ 3.30	+ 3.58
100 mc	− .03	+ .33	+1.28	+ 1.95	+ 2.97	+ 3.92	+ 4.41	+ 4.79	+ 5.03
200 mc	+ .10	+ .91	+1.97	+ 2.85	+ 4.11	+ 5.27	+ 5.84	+ 6.26	+ 6.47
500 mc	+ .30	+1.46	+2.89	+ 4.04	+ 5.61	+ 7.08	+ 7.76	+ 8.22	+ 8.38
1 c	+ .42	+1.86	+3.57	+ 4.94	+ 6.75	+ 8.43	+ 9.19	+ 9.69	+ 9.82
2 c	+ .56	+2.27	+4.27	+ 5.84	+ 7.87	+ 9.78	+10.63	+11.16	+11.25
5 c	+ .75	+2.81	+5.19	+ 7.03	+ 9.39	+11.58	+12.54	+13.12	+13.17
10 c	+ .89	+3.22	+5.87	+ 7.94	+10.52	+12.94	+13.98	+14.59	+14.60
20 c	+1.03	+3.63	+6.57	+ 8.84	+11.67	+14.31	+15.43	+16.08	+16.06
50 c	+1.21	+4.17	+7.47	+10.02	+13.16	+16.09	+17.33	+18.02	+17.95
100 c	+1.35	+4.58	+8.18	+10.93	+14.31	+17.46	+18.78	+19.51	+19.41
Danger Range	plus	plus	plus	plus	plus	plus	plus	plus	plus
20 cm	+.64	+1.90	+3.22	+4.19	+5.28	+6.31	+6.70	+8.68	+6.70
50 cm	+.28	+ .83	+1.39	+1.83	+2.32	+2.76	+2.93	+3.00	+2.93
1 m	.00	.00	.00	.00	.00	.00	.00	.00	.00
2 m	−.28	− .83	−1.39	−1.83	−2.32	−2.76	−2.93	−3.00	−2.93
5 m	−.64	−1.90	−3.22	−4.19	−5.28	−6.31	−6.70	−6.86	−6.70
10 m	−.92	−2.71	−4.60	−5.98	−7.55	−9.02	−9.57	−9.80	−9.57
Working Time	plus	plus	plus	plus	plus	plus	plus	plus	plus
1 hr. day	−.41	−1.22	−2.08	−2.69	−3.40	−4.06	−4.31	−4.41	−4.31
2	−.28	− .81	−1.37	−1.79	−2.26	−2.70	−2.87	−2.94	−2.87
4	−.14	− .14	− .69	− .90	−1.14	−1.35	−1.44	−1.47	−1.44
8	.00	.00	.00	.00	.00	.00	.00	.00	.00
24	+.18	+ .53	+1.10	+1.17	+1.48	+1.76	+1.87	+1.92	+1.87
Absorber	times	times	times	times	times	times	times	times	times
Pb	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe	4.75	2.68	2.11	1.75	1.51	1.53	1.53	1.53	1.77
Al*	17.23	7.71	5.43	5.13	4.70	4.25	4.81	5.22	6.01
H_2O	35.00	17.80	12.50	11.15	9.93	10.00	11.20	12.35	14.13

* Or concrete.

EXAMPLE: An iron shield is required for manipulation of 500 mc of radioactive material emitting 1.5 Mev gamma rays at a minimum working distance of 50 cm, and for two hours per day.

Shielding thickness = (7.08 (basic entry)
+ 2.76 (correction for danger range)
− 2.70 (correction for 2 hr/day))
× 1.53 cm Fe (conversion from Pb to Fe)
= 10.9 cm Fe

Major Classes of Uranium Deposits

URANIUM COMPOSES about 0.0004% of the earth's crust, but it occurs very sparingly in significant concentrations. There are five major classes of uranium deposits which are being exploited now or will be exploited in the future:

1. High-grade pitchblende-radium deposits [assaying better than 1% uranium oxide (U_3O_8) in quantity worth mining] occurring as replacement bodies. Where oxidized, the ore consists of autunite, carnotite, and other oxidation products of pitchblende, many of which are brightly colored. The better known deposits of this kind are Eldorado in Canada; Shinkolobwe in the Belgian Congo (from both of which the United States obtains uranium); and Joachimstahl and other deposits in the Erzgebirge district of Czechoslovakia and Germany which, according to newspaper accounts, Russia is exploiting. Deposits of this class may contain appreciable quantities of silver, copper, or cobalt.

2. Carnotite-type and roscoelite-type vanadium-uranium ores of the Colorado plateau. These closely related ore types are apparently important only in this country, but at best they are quite inferior to the high-grade ores as a source of uranium. These deposits occurring in flat-lying sandstones are under active development as part of the commission's program. Ore acceptable at AEC ore purchase depots contains a minimum of 0.10% U_3O_8, and payment is made for vanadium (V_2O_5) content in a ratio not exceeding 10 parts V_2O_5 to one part U_3O_8. By-product uranium from privately owned vanadium plants is also purchased by the commission.

3. Gold-uranium ores of the Witwatersrand, South Africa. Public announcement has been made of the occurrence of uranium as a very minor constituent of the gold-bearing Witwatersrand conglomerate. The prospect exists of future by-product uranium from the great gold mining industry of the Union of South Africa. The commission, through the U. S. Geological Survey, has been systematically examining all of the mill and smelter products in this country to discover if similar by-product possibilities exist here.

4. Uranium-bearing oil shales and other marine sediments. It has long been known that certain oil shales and other marine sediments, including phosphatic beds, contain very small quantities of uranium. Sweden, for example, has announced that she is building a small atomic pile and intends to derive uranium from her oil shales to feed this pile. According to published statements Swedish shale deposits containing many millions of tons of "ore" run around 0.02% U_3O_8. (These same geological formations extend northeastward up through Estonia and Leningrad.) By-product uranium from oil shale or phosphate industries may play a part in the development of atomic energy in different parts of the world. The AEC expects to exhaust every possibility of this character in the United States.

5. Miscellaneous other deposits. Pegmatites containing small amounts of pitchblende; placers containing a little uranium (generally as thorianite) along with monazite, and other ore types of as yet minor importance.

—From a release by U.S. Atomic Energy Commission

Table XII. Nuclear Radiation and its Detection

TYPE OF RADIATION	ELECTRICAL CHARGE	SOURCE	AVERAGE ENERGY	COMPARATIVE RANGE IN AIR	HOW DETECTED
Gamma rays	None	Natural and induced Radioactive Material	50 Kev to 3 Mev	Thousands of times alpha	Ionization Chamber, Geiger Counter, Scintillation Crystal, Photographic Film
X-rays	None	Bombardment of a metal target by Cathode Rays	20 Kev to 100 Mev	Similar to gamma	Similar to gamma
Cosmic Rays	Complex rays; may be composed of +,- and neutral particles & gamma rays	Natural nuclear reactions throughout the universe	1 Bev and higher	Most penetrating of all types of radiation	Geiger Counter, Wilson Cloud Chamber
Alpha	Double positive	Nuclear disintegration of the higher atomic number elements and their isotopes	3-10 Mev	4 cm at 5 Mev. Easily absorbed by air or any thin-walled material	Proportional counter, scintillation counter
Beta	Negative	Natural and induced Radioactive Material	50 Kev to 3 Mev	A few hundred times alpha	Geiger counter, proportional counter
Mesons	Positive or negative	Associated with Cosmic rays	Above 100 Mev	See Cosmic rays (above)	Wilson Cloud Chamber
Neutrons	None	Atomic fission Bombardment of some elements with high energy particles	About 1 Mev Thermal velocities to 1 Mev & higher	Slowed down by carbon, deuterium, beryllium Extremely penetrating in air	Boron-coated ionization chamber, proportional counters containing boron gas
Protons	Positive	Ionization of Hydrogen	Depends on accelerator	About ten times alpha rays	Any
Positrons	Positive	Induced radioactive materials	50 Kev to 2 Mev	Similar to beta rays	Wilson Cloud Chamber, Geiger Counter
Deuterons	Positive	Ionization of Deuterium (Heavy hydrogen)	Depends on accelerator	About 10 times alpha rays	Any
Neutrino (theoretical)	None	Accompanies beta rays	Complementary to beta particle	Unknown	None

APPENDIX VI

FALL-OUT

When an atomic bomb explodes the enormous amount of heat generated causes a rapid rise of air. After the blast air rushes back into the point of explosion from every outward direction to take the place of the rapidly rising cloud of air. This rushing in of the air or inward wind reaches hurricane strength.

If the bomb explodes near the ground the inward wind will pick up a large amount of dust from the earth's surface and carry it into the cloud which is radioactive. Here the minute particles of fission products, unfissioned materials, and the artificially created radio active substances attach themselves to the larger dust particles brought up from the ground by the inward wind.

As the upward rush of air subsides the existing winds of the area tend to blow the cloud column away. Also, the contaminated dust particles begin to fall slowly to the earth. Usually, we expect two different masses to fall at the same velocity, but the resistance of air to small particles slows down the lighter ones more than it does the heavier ones. Thus, the heavier particles fall a little faster than do the lighter particles, causing a spread of contamination. This falling to the earth of the contaminated dust is often called "fall-out."

AIR BURST

It is to be noted that if the bomb explodes high in the air the inward wind toward the point of explosion does not pick up much dust from the ground. Thus, the small radioactive particles in the cloud have fewer larger particles to attach themselves to and are blown away, being scattered over such a wide area that the concentration is negligible.

SUBSURFACE BURST

A large quantity of debris and dust is carried up by a subsurface burst. Furthermore, the column does not rise as high as does the column after other type bursts. Hence, serious contamination is expected from fall-out after a subsurface burst. See figure 48.

SURFACE BURST

A considerable amount of dust, but less than for a subsurface burst, is picked up from the surface of the earth by the inward wind immediately after a surface burst. Fall-out after a surface burst will cause some serious contamination. However, the fall-out will be less serious than that of a subsurface burst. See figure 49.

At different altitudes, even the same locality, the direction of the wind differs. This change of wind direction encountered by the falling particles will complicate, slightly, the calculation or prediction of a fall-out area (see fig. 52). However, with the proper wind data which can be obtained from the Air Weather Service, a radiological defense officer can calculate fairly accurately the probable fall-out area. The method of making these plots now is being taught in the service schools which are training officers to become radiological defense staff personnel.

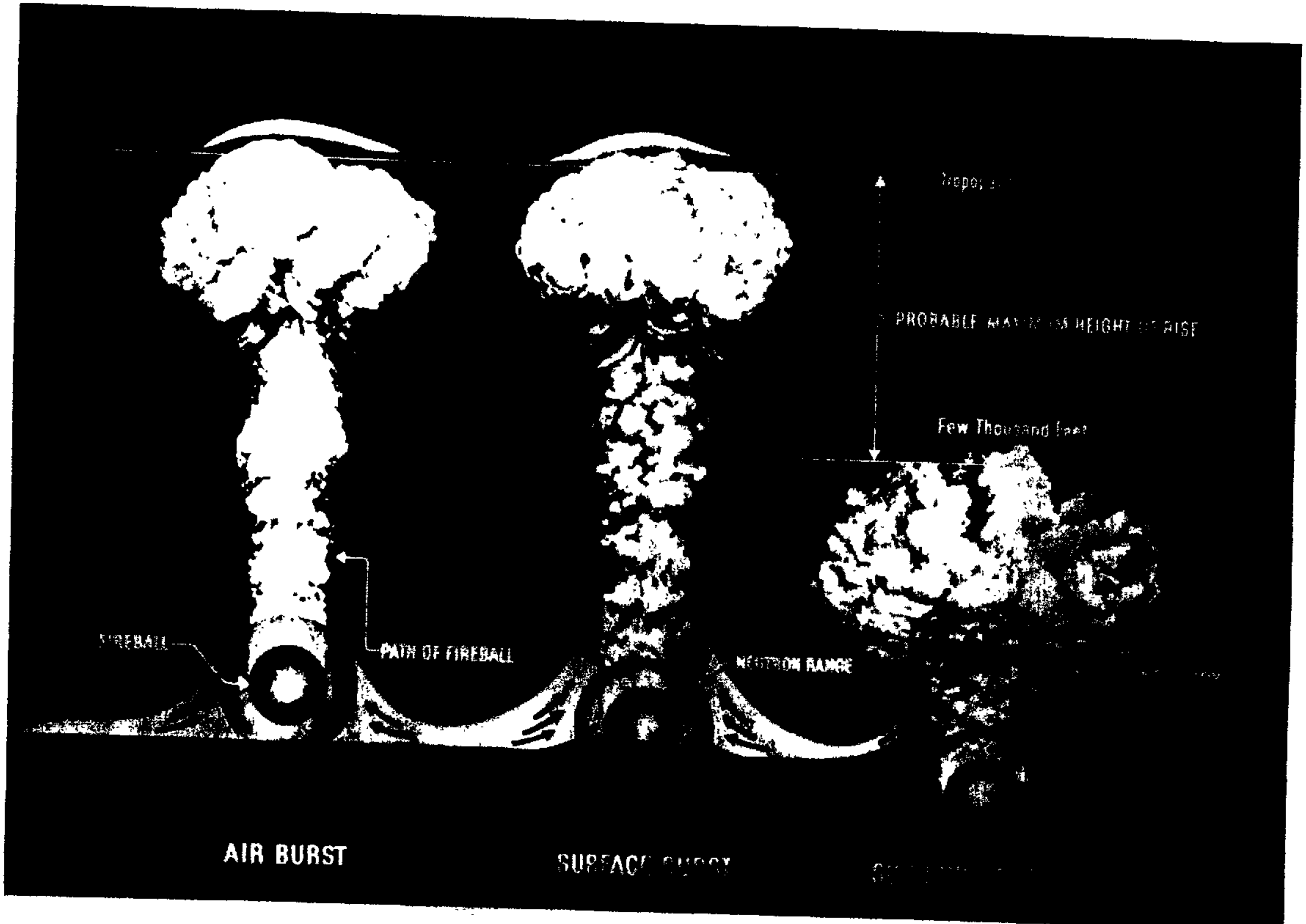


Figure 47. Typical atomic bomb bursts.

Figure 47. Typical atomic bomb bursts.

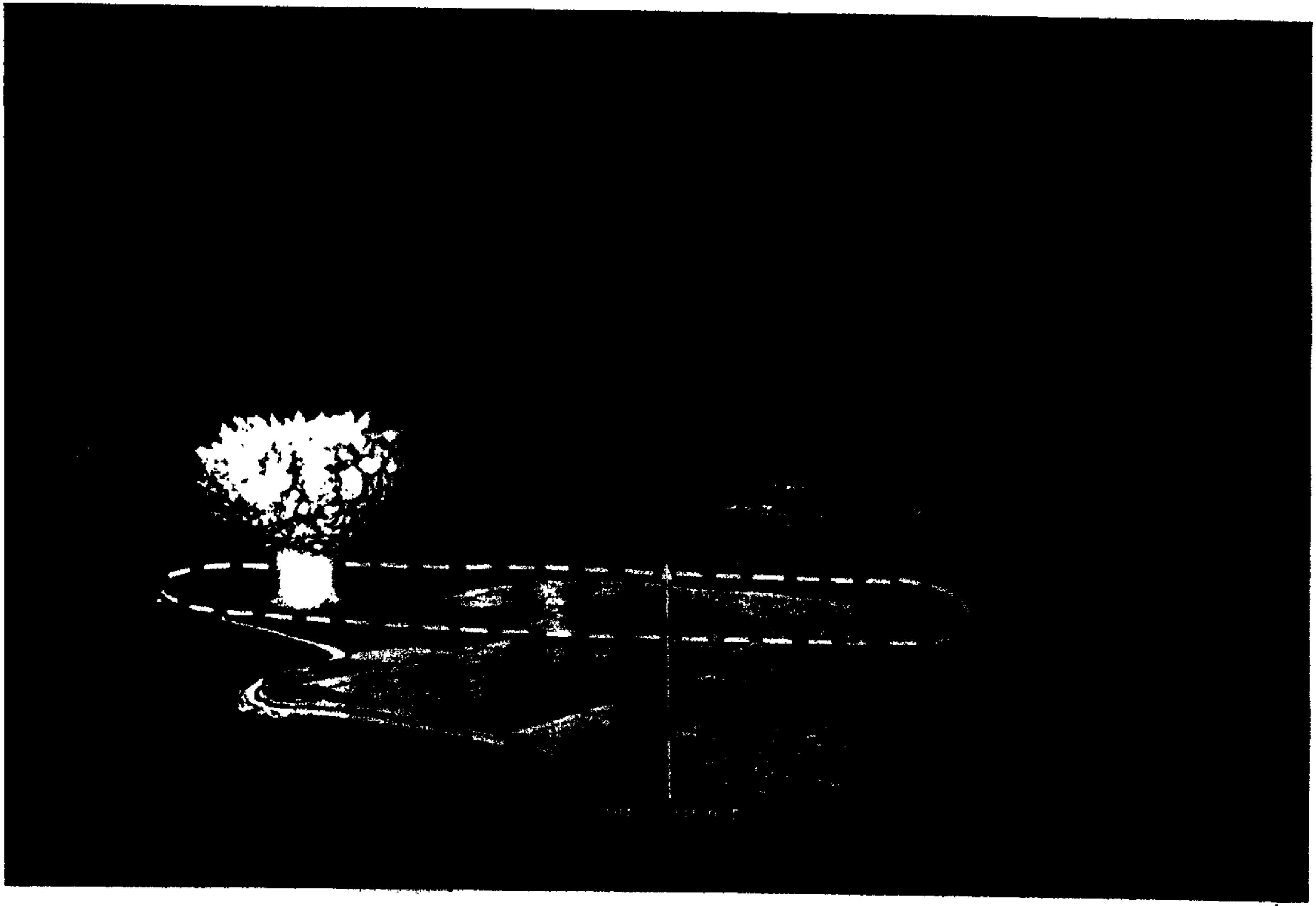


Figure 48. Sub-surface burst.

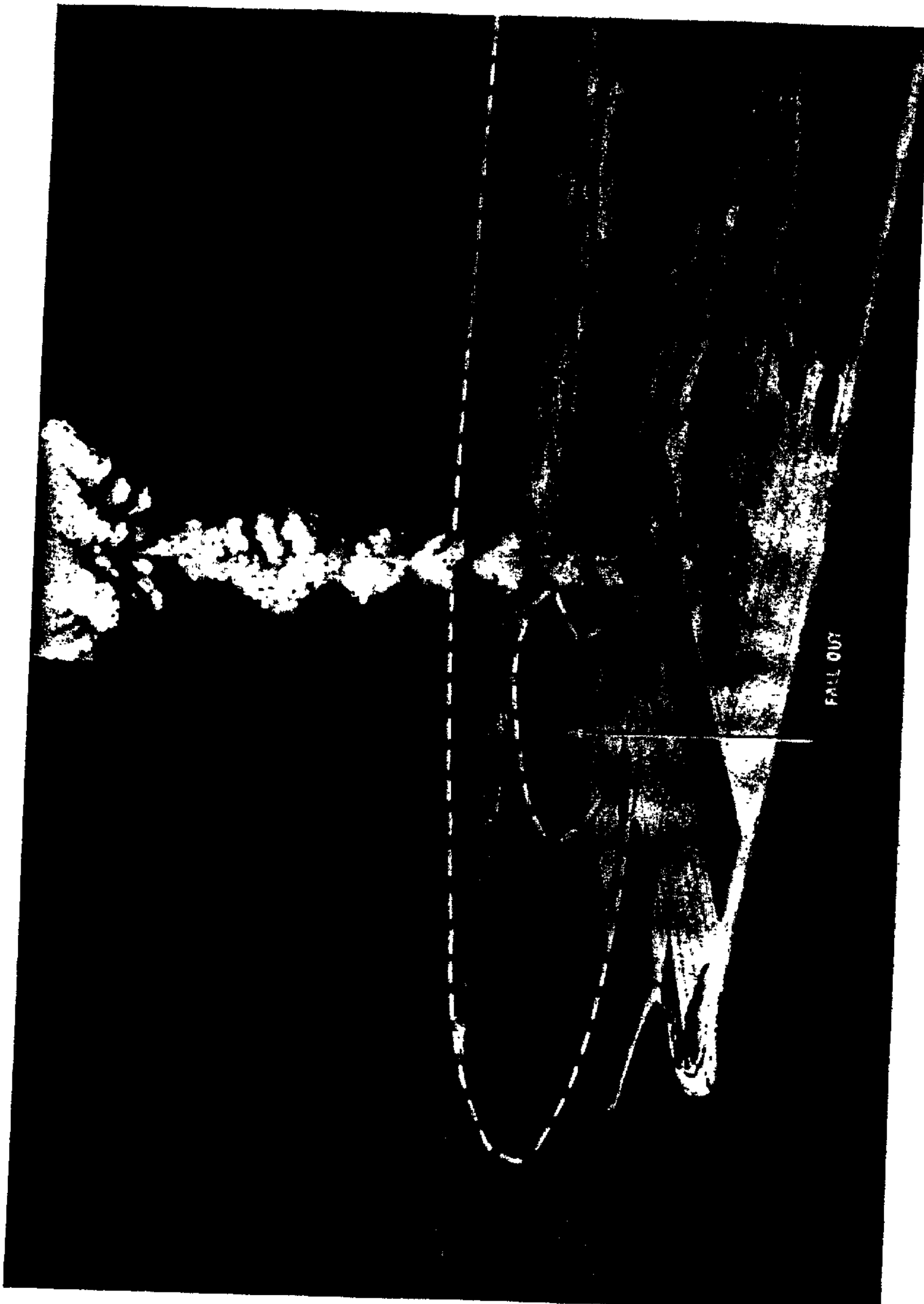


Figure 49. Surface burst.

Figure 49. Surface burst.

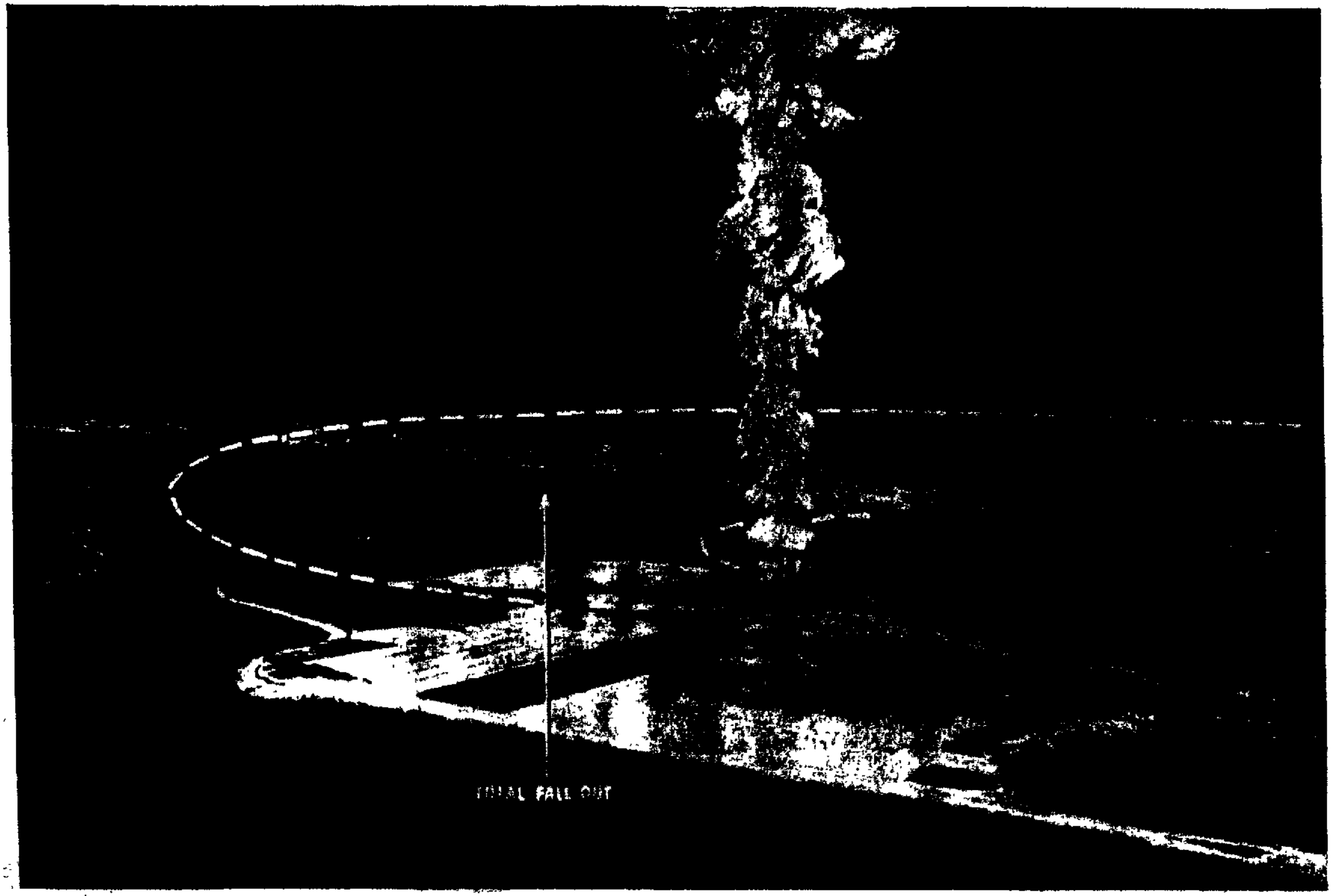


Figure 50. Air burst.

APPENDIX VII

DEPARTMENT OF THE ARMY PLAN FOR RADIOLOGICAL DEFENSE

Section I. INTRODUCTION

1. **General.** *a.* The advent of the atomic bomb has introduced into military planning the problem of dealing with, and providing defense against, the radiological hazards produced by weapons of this type.

b. While the atomic bomb is capable of producing heat and blast damage of unprecedented magnitude, its unique feature is the release of enormous quantities of nuclear radiations in the form of gamma rays, neutrons, alpha particles, and beta particles at the instant of and subsequent to detonation.

c. At the instant of detonation, the radiological hazard is due almost entirely to the penetrating shower of neutrons and gamma rays produced by the nuclear explosion. Other nuclear radiations are emitted at this time, but are relatively unimportant in comparison with the neutrons and gamma rays. The emission of neutrons ceases almost immediately following the explosion, and the radiological hazard subsequent to detonation is attributable to the combined effect of the radioactivity produced by the fission products resulting from the nuclear fission of the bomb material, the unfissioned material or bomb residue, and the radioactivity induced in certain materials in or near the target area by the neutrons from the explosion.

d. Since the effective persistency of the radiation hazards created by atomic weapons or radiological weapons may range from fractions of a second to many years, depending upon the half-lives of the radioactive substances present, radiological defense measures must include the detection, isolation, and/or decontamination of areas and matériel contaminated with radioactive materials.

e. The inability of the physical senses to detect the presence of nuclear radiations and the casualty-producing effects of these radiations require that suitable countermeasures, including special equipment and techniques, be devised to protect personnel and material against the hazards of radioactivity.

2. **Definition.** Radiological defense is defined as the protective measures taken to minimize personnel and matériel damage from radioactivity, and is interpreted to include measures such as—

a. Training, organization, and distribution of personnel.

b. Development, provision and maintenance of fixed and portable structures and equipment.

c. Development of techniques and procedures including use of detecting equipment, protection or removal of exposed personnel, and decontamination of personnel, equipment, structures, or terrain. A glossary of terms pertinent to this plan is attached to appendix A.

3. **Purpose of plan.** The purpose of this plan is to establish a radiological defense organization within the Department of the Army which will provide for—

a. The protection of Army personnel, units, and establishments against the effects of radioactivity, and the maintenance of the operational efficiency of the Army in the presence of radiological hazards.

b. The support of civil radiological defense control and relief measures in accordance with the Army's established policies for providing assistance to civil authorities in connection with disaster relief operations.

4. **Scope of Plan.** Consistent with the definition of radiological defense, this plan is concerned only with the Army-wide organization, training, and application, of countermeasures required to minimize personnel injury and matériel damage which may result from exposure to radiological hazards. No attempt is made in this plan to specify organization, responsibility, or operating procedures in the broader field of atomic defense, of which radiological defense is a part. Atomic defense will involve the coordinated and usually simultaneous application of countermeasures to mitigate the effects of blast, fire, and flood, as well as those of radioactivity, and is beyond the scope of this plan.

Section II. RESPONSIBILITIES

5. **Command Responsibilities.** The radiological defense training of the unit and of the individuals in the unit, and the protection of the unit against radiological hazards, are basic responsibilities of command.

6. **Responsibilities of Department of the Army Agencies.** *a.* In the implementation of the Army radiological defense program, responsibility for operational control measures, training procedures, research and development, and logistical support will be charged, wherever possible, to those Department of the Army agencies now performing similar functions within their established fields of responsibility.

b. Certain fields of responsibility with respect to radiological defense organizational and training functions are enumerated in appendix "B."

c. Fields of responsibility pertaining to research and development activities in the field of radiological defense, and to the logistical support of the Army radiological defense program, will be determined and promulgated by the Assistant Chief of Staff, G-4, Logistics, General Staff, United States Army.

Section III. ORGANIZATIONAL STRUCTURE

7. **Basic Organizational Policy.** The enemy employment of atomic or radiological weapons may present a simultaneous need for many, or all of the countermeasures normally applied against other types of enemy action. In view of this possibility, and in the interests of effecting the maximum utilization of personnel and facilities, the Army organization for radiological defense will be included, wherever possible, within the framework of existing organizations dealing with command, training, logistical support, and operational control measures designed to counter enemy action.

8. **Expansion of Gas Defense Organization to Include Radiological Defense.** The functions of the present Army organization described in FM 21-40 for defense against chemical attack will be expanded to include radiological defense, thus providing specially trained personnel at all levels of the military structure to assist and advise commanders in radiological defense planning and action.

9. **Radiological Defense Function of Chief, Chemical Corps.** The Chief, Chemical Corps, as a technical staff officer of the Department of the Army, will be the adviser to the Secretary of the Army, the Chief of Staff, and all elements of the Army on all matters pertaining to the non-medical aspects of radiological defense. In this connection, he will be responsible for preparing and promulgating training doctrine, except for those phases of the program which pertain essentially to the medical aspects of radiological defense; conducting special service schools; and recommending Armywide technical inspection of training in radiological defense.

10. **Echelons of Non-Medical Radiological Defense Duties.** This expansion of the functions of the existing chemical defense organization will provide for the delegation of radiological defense duties to staff chemical officers and unit gas personnel, as indicated below:

a. Staff radiological defense officers (staff chemical officers).

(1) *Field armies.* At division and higher headquarters, radiological defense duties will be delegated to the staff chemical officer

who will serve as the technical adviser to the commander and staff in such matters.

(2) *Service elements.* At headquarters of all communications zone and zone of the interior service elements, radiological defense duties will be delegated to the staff chemical officer, who will serve as the technical adviser to the commander and staff in such matters.

(3) *Posts, camps, and stations.* At posts, camps, and stations, radiological defense duties will be delegated to the post chemical officer, who will serve as the technical adviser to the post commander in such matters.

b. Unit radiological defense officers (unit gas officers). Below divisional level, radiological defense duties will be performed by the unit gas officers. As prescribed in FM 21-40, each combat or service brigade, regiment, battalion, company, or similar units, will have a minimum of one qualified unit radiological defense officer (unit gas officer), and a minimum of one qualified alternate, appointed from assigned personnel by the unit commander. Additional alternates will be appointed, wherever possible, and all officers so appointed will be qualified to perform their radiological defense duties by completion of a prescribed course of training.

c. Unit radiological defense noncommissioned officers (unit gas noncommissioned officers). Below divisional level, unit radiological defense noncommissioned officers (unit gas noncommissioned officers) will assist unit radiological defense officers in performing radiological defense duties. As prescribed in FM 21-40, each combat or service brigade, regiment, battalion, company, or similar units, will have unit radiological defense noncommissioned officers (unit gas noncommissioned officers) appointed on the following basis, by the unit commander:

(1) *Brigade or similar unit.* Minimum of one unit radiological defense noncommissioned officer (unit gas noncommissioned officer).

(2) *Regiment or similar unit.* Minimum of one unit radiological defense noncommissioned officer (unit gas noncommissioned officer).

(3) *Battalion or similar unit.* Minimum of one unit radiological defense noncommissioned officer (unit gas noncommissioned officer).

(4) *Company or similar unit.* Minimum of two unit radiological defense noncommissioned officers (unit gas noncommissioned officers).

At least one alternate will be appointed for each unit radiological defense noncommissioned officer required, and all appointees will be qualified to perform their radiological defense duties by completion of a prescribed course of training. Unit radiological defense noncommissioned officers (unit gas noncommissioned officers) will be selected from individuals of the first four grades.

11. Increased Functions of Staff Chemical Officer. The present job description covering the position of staff chemical officer (SSN 7314) will be expanded to include radiological defense functions. Unit gas officers and unit gas noncommissioned officers will perform both chemical and radiological defense duties in addition to their primary duty assignments.

12. Additional Radiological Defense Positions. In addition to the radiological defense positions enumerated in paragraph 10, which will evolve from the adoption of the present organization for defense against chemical attack, studies of the radiological defense requirements of the Army indicate an apparent need for augmentation of this basic organizational structure. As a result of these studies, the following additional types of radiological defense positions will be provided for in the Army organization:

a. Radiological defense engineers. These specially trained officers normally will be assigned to duty with the staff chemical sections of theater of operations headquarters, communications zone headquarters, and other major headquarters, on the basis of individual requirements, and will serve as advisers and technical experts in all matters pertaining to the nonmedical aspects of radiological defense. The position of radiological defense engineer will be a primary duty assignment, and will be filled by officers who have completed a prescribed course of postgraduate and field training.

b. Radiological defense medical officers. These specially trained officers normally will be assigned to duty with the staff medical sections of theater of operations headquarters, communications zone headquarters, and other major headquarters, on the basis of individual requirements, and will serve as advisers in all matters pertaining to the medical aspects of radiological defense. The position of radiological defense medical officer will be a primary duty assignment, and will be filled by officers who have completed a prescribed course of postgraduate training.

c. Radiological defense monitors. Trained enlisted personnel will be required to assist unit radiological defense officers and unit radiological defense noncommissioned officers in performing instrument surveys and obtaining radiological data in areas contaminated, or suspected of being contaminated with radioactive materials. Radiological defense monitors will perform this duty in addition to their primary duty assignments. Each combat or service regiment, battalion, company, and similar units, will have radiological defense monitors appointed by the unit commander, on the following basis:

(1) *Regiment or similar unit.* Minimum of one radiological defense monitor.

(2) *Battalion or similar unit.* Minimum of one radiological defense monitor.

(3) *Company or similar unit.* Minimum of two radiological defense monitors.

At least one alternate will be appointed for each radiological defense monitor required. Radiological defense monitors will be selected from individuals below the first four grades, and will be qualified to perform their duties by completion of a prescribed course of training. So far as practicable, all unit personnel will be trained in monitoring operations and techniques so as to insure the availability, at all times, of individuals qualified to operate radiation detection instruments and devices in an emergency.

d. Radiological instrument repairman. Organizational, field, and depot maintenance on radiological equipment will be performed by radio repairmen who have received instruction in the maintenance and repair of radiological detection instruments. The chief signal officer will provide for the training of these repairmen, and also will prepare doctrine pertaining to the maintenance of electronic radiological instruments utilized by all elements of the Army. Radiological instrument repairmen who have had this specialized training will be required at all echelons to perform organizational, field, and depot maintenance on radiation detection instruments and devices used by the Army. Certain phases of organizational maintenance including calibration of instruments and replacement of defective or worn out batteries can be performed by radiological defense monitors, under the general supervision of unit defense personnel.

e. Radiological defense medical laboratory officer. An MSC officer trained at the postgraduate level in radio-chemistry, biology, bio-assay, and allied radiation fields. Such officers will supervise bio-assay laboratories.

f. Radiological defense laboratory technician (medical). Enlisted technician of the Army Medical Service trained in the techniques peculiar to biological, radio-assay laboratories.

g. Radiological defense laboratory technician (nonmedical). Enlisted technician trained in radio-chemistry analysis and radiation measurement.

13. **Agencies Requiring Radiological Defense Trained Personnel.** It is envisaged that the following Department of the Army agencies responsible for providing guidance with respect to organization, research and development, procurement and supply of equipment, preparation of training material, development of operational techniques, and formulation of policy, will have a requirement for personnel trained in radiological defense measures and techniques:

a. Assistant Chief of Staff, G–1, Personnel, General Staff, USA.

b. Assistant Chief of Staff, G–2, Intelligence, General Staff, USA.

c. Assistant Chief of Staff, G–3, Operations, General Staff, USA.

d. Assistant Chief of Staff, G–4, Logistics, General Staff, USA.

e. Office, Chief, Army Field Forces.

f. Chemical Corps.

g. Corps of Engineers.

h. Military Police Corps.

i. Army Medical Service.

j. Ordnance Corps.

k. Quartermaster Corps.

l. Signal Corps.

m. Transportation Corps.

14. **Job Descriptions of New Radiological Defense Positions.** Proposed job descriptions summarizing the duties of each category of radiological defense personnel referred to in paragraphs 10 and 12, are attached as appendix C.

Section IV. PERSONNEL REQUIREMENTS

15. . . . . .

16. **Expansion of Functions.** As indicated in section III above, requirements for radiological defense personnel other than radiological defense engineers, and radiological defense medical officers, can be satisfied through the expansion of an existing military occupational specialty to include radiological defense duties in the instance of the staff chemical officer, and through the delegation of radiological defense functions to certain unit personnel in addition to their primary duty assignments. The positions of radiological defense engineer, radiological defense medical officer, radiological defense medical laboratory officer, radiological defense laboratory technician (medical) and radiological defense laboratory technician (nonmedical), however, will constitute a requirement for additional personnel, and for the inclusion of these new military occupational specialties in applicable tables of organization and equipment.

Section V. TRAINING REQUIREMENTS

17. **Scope of Army-Wide Training.** Army-wide training in radiological defense measures and techniques will include training in individual, collective, and tactical protection; training in the medical aspects of radiological defense; training in radiation detection instrument maintenance and repair; and the training of personnel in such other fields as may be found necessary to satisfy any special requirements of the radiological defense program.

18. **Thoroughness of Training.** To prove effective, this training must be included in all individual and unit training programs, integrated throughout the Army school system, and coordinated to the maximum extent possible with the courses of instruction offered at comparable Navy and Air Force schools.

19. **Coverage of Radiological Defense Training.** To satisfy these requirements, the training of Army personnel in radiological defense measures and techniques will range from the basic, nontechnical indoctrination given to every individual, through the several levels of military technical training required to qualify individuals who will fill operational positions in the radiological defense organization, to the advanced or specialized postgraduate training of radiological defense engineers and radiological defense medical officers.

20. **Implementation of Army-Wide Training Program.** The Army-wide training program will be implemented by incorporating appropriate radiological defense instruction in all troop training, in the program of instruction for the Reserve Officers' Training Corps, and in the curricula of the United States Military Academy and the several special and general service schools; through the use of extension courses; and through the establishment of special courses of instruction for radiological defense personnel. At the advanced education or postgraduate level, the training facilities provided by service schools will be augmented, as required, by utilizing civilian educational institutions and training agencies.

21. **Extent of Training for Army Medical Service Personnel.** The radiological defense training of personnel of the Army Medical Service will parallel that provided for non-medical personnel, and will range from basic indoctrination to a postgraduate level of instruction which will correspond to that provided for radiological defense engineers. Insofar as practicable, all Medical Corps officers will receive training corresponding to that given to staff radiological defense officers and/or unit radiological defense officers, with supplemental training in the pathological and clinical aspects of radiological warfare. The balance of Army Medical Service personnel will receive appropriate indoctrination in both the medical and non-medical aspects of radiological defense. Such training will be as prescribed by The Surgeon General.

22. **Means of Training Reserve Components.** The training of personnel in the Reserve components of the Army will be limited in general to the basic indoctrination and the military technical training levels, and will be accomplished through the medium of extension courses, special short courses of instruction at special service schools, and the indoctrination material included in

the curricula of the associated courses offered by the special and general service schools.

23. . . .

24. . . .

25. . . .

26. **Additional Specialist Training.** It is expected that Department of the Army agencies charged with specific responsibilities in the field of radiological defense will train personnel to satisfy their individual requirements for technical specialist in the same manner that they now train research and other specialist personnel with respect to their presently established fields of responsibility.

Section VI. LOGISTICAL REQUIREMENTS

27. **Requirement for Instruments and Equipment.** While detailed specifications covering the equipment and supplies which will be needed to support the Army radiological defense organization have not yet been developed, a requirement is indicated for radiation detection instruments, and for certain general types of individual and collective protective equipment.

28. **Instrumentation.** *a.* Since the physical senses are incapable of detecting the presence of even intense fields of ionizing radiation prior to the time that physical damage has been incurred by the individual, the detection and measurement of nuclear radiations is entirely dependent upon the proper use of suitably designed instruments.

b. The limited experience gained to date in the field use of radiation detection instruments indicates an initial military requirement for (*a*) an instrument which will provide an instantaneous reading of radiation intensity at a given point and will satisfy the need for a survey instrument to detect the presence of, and measure the intensity of, radiation in areas contaminated with radioactive materials; and for (*b*) an instrument or device capable of registering the cumulative amount of radiation received during a given time interval and providing a means of determining the degree to which personnel have been exposed. In the interests of simplifying training within the Armed Forces in the use of radiation detection instruments and providing for the interchangeability and efficient utilization of such equipment when required, the standardization of radiation detection instruments and devices will be effected on a joint Army-Navy-Air Force basis, insofar as possible.

c. In view of the fact that the standardization of radiation detection instruments and devices for military use has not been accomplished to date, this plan does not include specific recommendations relative to T/O&E allowances of such equipment. . . .

29. **Individual Protection.** The seriousness of the internal radiation hazard, which can result from the inhalation, ingestion, or injection of radioactive particles into the blood stream through breaks in the skin, indicates a requirement for a protective mask which will prevent the inhalation of such particles, and for some type of protective clothing which will protect the body from direct contamination with radioactive materials.

30. **Collective Protection.** A requirement is indicated for some type of collective protector similar to those now used for protection against chemical agents, or some type of inclosed air conditioning system, for the protection of vital installations and underground shelters. Equipment of this type will be required to prevent the entry of airborne radioactive materials into the ventilating systems of structures and installations which otherwise may furnish adequate protection against the effects of atomic or radiological weapons.

31. **Use of Available Gas Defense Equipment.** Pending the further development of individual and collective protective equipment, gas masks, protective clothing, and associated items of available gas defense equipment will be utilized to satisfy radiological defense requirements.

32. **Responsibility for Procurement and Supply of Equipment.** The procurement and supply to the Army of radiological defense equipment and supplies will be carried on under the general supervision of the Assistant Chief of Staff, G-4, Logistics, General Staff, United States Army, and will be charged by the Assistant Chief of Staff, G-4, Logistics, to Army agencies currently performing similar functions within their established fields of responsibility.

Section VII. RESEARCH AND DEVELOPMENT

33. **Research and Development.** Research and development pertaining to radiological defense measures, equipment, and supplies, will be carried on under the general supervision of the Assistant Chief of Staff, G-4, Logistics, General Staff, United States Army, in coordination with the Armed Forces Special Weapons Project, and will be charged by the Assistant Chief of Staff, G-4, Logistics, to Army agencies currently performing similar functions within their established fields of responsibility.

Section VIII. INTELLIGENCE

34. **Supervision of Intelligence on Foreign Radiological Material.** The collection and evaluation of information and matériel pertaining to foreign radiological measures, techniques, and capabilities, both offensive and defensive, will be carried on under the supervision of the Assistant Chief of Staff, G-2, Intelligence, General Staff, United States Army, and will be effective through normal intelligence channels.

35. **Responsibility for Technical Intelligence on Foreign Materiel.** As prescribed in FM 30-15, as amended, orders defining the responsibility for the design of United States weapons and military equipment will govern the delineation of primary responsibility between the services for the production of technical intelligence on similar items of foreign matériel. The service having design responsibility will coordinate with other services who may have procurement or operating responsibility.

APPENDIX A

GLOSSARY OF TERMS

1. *Atomic weapon*—A weapon, either explosive or nonexplosive employing nuclear energy.

2. *Radiological weapon*—An atomic weapon in which radioactive substances are employed primarily to create hazards by utilizing radiation to injure enemy personnel or to contaminate material.

3. *Atomic warfare*—Warfare involving the employment of atomic weapons.

4. *Radiological warfare*—Radiological warfare is described as the offensive and defensive use of radioactivity in warfare. The offensive phase includes the use of radioactive materials and atomic bombs when used primarily for their radioactive effect. It also includes the secondary radioactive effect of atomic bombs used primarily as blast or incendiary weapons. The defensive phase of radiological warfare encompasses the field of radiological defense.

5. *Radiological defense*—Protective measures to minimize personnel and matériel damage from radioactivity. This definition is interpreted to include measures such as: Training, organization, and distribution of personnel; development, provision, and maintenance of fixed and portable structures and equipment; use of detecting equipment; protection or removal of exposed personnel, and decontamination of personnel, equipment, structures, or terrain.

6. *Alpha (α) particle*—A positively charged nuclear particle emitted by certain naturally radioactive substances such as radium and uranium. Because of their short range and limited penetrating power, alpha particles are absorbed by the epidermis or outer skin with no resulting change in living tissues, and hence do not present an external radiation hazard. On the other hand, alpha emitting materials constitute a serious and delayed internal radiation hazard if they are taken into the body through inhalation or ingestion, or through open wounds in the skin.

7. *Beta (β) particle*—A positively or negatively charged particle emitted by certain radioactive substances. Although the range of beta particles is greater than that of alpha particles, they do not provide a serious external radiation hazard at distances greater than a few feet from their source. As in the instance of alpha particles, beta emitting materials provide a serious internal radiation hazard if absorbed into the body through inhalation, ingestion, or open wounds. Close contact with a beta emitter or handling of beta contaminated objects with the bare hands can produce serious radiation damage to the skin and immediate underlying tissues.

8. *Gamma (γ) ray*—A penetrating, invisible radiation which travels at the speed of light and is emitted from the nuclei of certain radioactive atoms. Gamma rays are similar in character to X-rays, but are usually more penetrating due to their higher energies. Gamma radiation constitutes a serious external radiation hazard since it can be counteracted only by the interposition of thick shielding material between the source and the personnel to be protected. Lead, steel, concrete, and other common materials are capable of reducing the intensity of gamma rays, thus providing varying degrees of protection against this type of radiation. The degree of protection afforded is dependent upon the mass of the shielding material employed and the energies of the gamma rays.

9. *Neutron*—A nuclear particle bearing no net electrical charge. Although neutrons do not have as great an effective range in air as gamma rays, they present a more difficult shielding problem, and constitute a serious external radiation hazard.

10. *Fission*—The process by which the nucleus of an atom breaks into two to four main fragments, which are atoms of lighter materials, and emits several free neutrons. This process is accompanied by the release of a tremendous amount of energy which is imparted to the fragments of the original nucleus and to the neutrons which are emitted. Fission energy also is imparted to beta and gamma radiation.

11. *Fission product*—An element produced as a result of nuclear fission. Fission products are radioactive and emit beta particles, gamma rays, and, in some instances, neutrons.

12. *Unfissioned material*—Fissionable material which has not undergone fission. In the instance of an atomic bomb explosion, unfissioned material consists of that portion of the original bomb material which did not enter into the nuclear reaction. Unfissioned material is an alpha particle emitter.

13. *Isotopes*—Two or more forms of the same element which have the same chemical properties, but

different atomic weights. Certain isotopes are unstable or radioactive and, in the process of radioactive decay to a stable isotope of the same element or a different element, emit one or more types of nuclear radiations.

14. *Induced radioactivity*—Artificial radioactivity which may be produced in certain elements as the result of the capture of neutrons by these elements.

15. *Half-life*—A measure of rate of radioactivity decay. The half-life of a radioactive isotope is the period of time required for a given amount of that isotope to decrease to one-half its original amount as a result of natural radioactive disintegration. The half-life of a given isotope is a physical constant characteristic of that isotope, independent of the quantity of the isotope originally present, and unaffected by chemical changes and variations in temperature, pressure, etc. The half-lives of individual isotopes vary from fractions of a second to billions of years.

16. *Photodosimetry*—The use of photographic film to measure the total amount of ionizing radiation received over a given period of time. In general, photodosimetry operations include the use of personnel film badges, the developing of the film badges, and the determination, by means of photoelectric instruments (densitometers) or calibration charts, of the total amount of exposure recorded on the film.

APPENDIX B

RESPONSIBILITIES OF CHIEFS OF TECHNICAL SERVICES

1. **Chief, Chemical Corps.** *a.* Development of the over-all Army radiological defense organization.

b. Formulation, coordination, and promulgation of radiological defense training doctrine for the Department of the Army, except for those phases which pertain essentially to the medical aspects of radiological defense.

c. Technical advice pertaining to the training of the Army in radiological defense, and the conduct of special service schools required to qualify radiological defense personnel in conformity with the levels of training standardized by the Armed Forces Special Weapons Project, except for those phases of the training program conducted under the supervision of The Surgeon General, and the Chief Signal Officer.

d. Assistance to the Office of the Chief, Army Field Forces, in the development of tactical doctrine for the field army, and in the training of unit radiological defense personnel.

2. **The Surgeon General.** *a.* Formulation of Army-wide policies pertaining to the diagnosis, treatment (including patient decontamination), evacuation, and hospitalization of radiological casualties.

b. Administration of photodosimetry operations and records in conjunction with the Army-wide system of individual medical records and medical statistical reporting.

c. Training of Army Medical Service personnel in the medical aspects of radiological defense and treatment of radiological casualties.

3. **Chief Signal Officer.** *a.* Training of radiological instrument maintenance personnel to perform field and depot maintenance operations.

b. Preparation of Department of the Army doctrine on the care and use of electronic radiological instruments.

APPENDIX C

RADIOLOGICAL DEFENSE JOB DESCRIPTIONS

Staff Radiological Defense Officer (Staff Chemical Officer).

Note. The prescribed duties of staff chemical officers (SSN 7314) will be expanded to include the functions of staff radiological defense officers, as indicated below.

Advises commander and staff on radiological defense measures. Supervises and inspects, within limits prescribed by the commander, the radiological defense training of all units in the command; prepares the SOP for defense against radiological attack for the command; supervises, within limits prescribed by the commander, collective protective measures, including the reconnoitering of areas subjected to radiological attack or suspected of being contaminated with radioactive materials; provides technical advise with respect to the isolation and/or decontamination of areas and matériel contaminated with radioactive materials; examines captured radiological defense equipment, and collects and evaluates information concerning the status of enemy equipment and training; advices commander regarding quantity and condition of radiological defense equipment and supplies.

Radiological Defense Engineer

Note. This proposed job description covers a new military occupational specialty.

Serves as adviser and technical expert on all matters pertaining to the non-medical aspects of radiological defense. Prepares general policies and instructions relative to protection of personnel, facilities, and matériel from radiological attack, and coordinates such policies and instructions with radiological defense programs of other governmental and civilian agencies; supervises and inspects radiological defense training of subordinate units, and insures that units comply with directives establishing standards of instrumentation and personnel training; advises subordinate commands on technical problems pertaining to radiological defense measures and techniques; directs and coordinates efforts of agencies providing relief and assistance to areas subjected to radiological attack, including the evaluation of the radiological situation and the direction of decontamination operations; examines captured radiological defense equipment, and evaluates information concerning status of enemy radiological weapons, defense equipment, and training.

Radiological Defense Medical Officer.

Note. This proposed job description covers a new military occupational specialty.

Advises commander and staff on radiation hazards which may affect his command. Evaluates internal and external hazards of all types of ionizing radiation and their respective biological effects. Advises as to immediate, retarded and remote effects of radiation exposures of various dosages received. Evaluates hazards of food and water contaminated with radioactive materials. Supervises preparation and promulgation of necessary information on radioactive effects to lower echelons. Advises commander and staff on the medical aspects of the radiological training program.

Unit Radiological Defense Officer (Unit Gas Officer).

Note. In addition to the gas defense duties described in FM 21–40, unit gas officers will perform the functions of unit radiological defense officers, as indicated below.

Advises unit commander on radiological defense matters. Trains unit troop officers and noncommissioned officers in radiological defense measures, and assists, or supervises and conducts as the commander may direct, the radiological defense training of the unit; prepares the unit SOP for defense against radiological attack; assists in conducting regular inspections to determine adequacy of radiological defense training and the condition of protective equipment; advises in the care of protective equipment; supervises unit radiological defense noncommissioned officers and radiological defense monitors in conducting reconnaissance of areas subjected to radiological attack or suspected of being contaminated with radioactive materials; suggests methods of dealing with contaminated areas and matériel; supervises decontamination operations as directed; collects information pertaining to enemy radiological defense equipment and activities; advises unit commander regarding quantity and condition of radiological defense equipment and supplies; and supervises organizational maintenance of all such equipment and supplies.

Unit Radiological Defense Noncommissioned Officer (Unit Gas Noncommissioned Officer).

Note. In addition to the gas defense duties described in FM 21-40, unit gas noncommissioned officers will perform the functions of unit radiological defense noncommissioned officers, as indicated below.

Assists unit radiological defense officer in performing his duties. Assists in training unit personnel in methods of individual and collective protection to be employed in the event of radiological attack, assists in conducting periodic inspections to insure that all unit personnel are properly informed and proficient in the application of radiological defense measures; demonstrates use of radiation detection instruments and devices, supervises radiological defense monitors in surveying areas subjected to radiological attack or suspected of being contaminated with radioactive materials; checks readings on dosimeters periodically, and collects and transmits film badges used by unit personnel to the prescribed agencies; assists in supervision of decontamination operations as directed, including personnel decontamination; maintains unit radiological defense equipment and inspects equipment at periodic intervals to check condition and quantity.

Radiological Defense Monitor.

Note. This proposed job description covers a new additional duty assignment.

Performs surveys, under supervision of unit radiological defense personnel, of areas subjected to radiological attack. Operates radiation detection instruments and devices to detect presence of, and measure the intensity of, radiation in areas contaminated with radioactive materials. Takes and records instrument readings, reporting findings to unit radiological defense personnel. Assists in decontamination operations, as directed.

Radiological Instrument Repairman.

Note. This proposed job description covers a new military occupational specialty.

Installs, inspects, tests, calibrates, maintains, and repairs all types of radiological detection instruments. Inspects and tests devices to detect cause of faulty operation. Locates trouble and makes necessary repairs and adjustments on various types of survey meters, dosimeters, and allied equipment. Improvises or makes substitutions for defective parts when exact replacements are not available.

Radiological Defense Medical Laboratory Officer.

Note. This proposed job description covers a new occupational specialty.

Selected MSC officers, trained at the postgraduate level in radio-chemistry, biology, bio-assay, and allied radiation fields, act as supervisors in the bio-assay laboratories of the Army Medical Service.

Radiological Defense Laboratory Technician (Medical).

Note. This proposed job description covers a new occupational specialty.

Selected enlisted technicians of the Army Medical Service especially trained in techniques peculiar to bio-assay laboratories, perform routine bio-assay work in Army Medical Service laboratories.

Radiological Defense Laboratory Technician (Non-Medical).

Note. This proposed job description covers a new occupational specialty.

Selected enlisted personnel, especially trained in radio-chemistry analyses and radiation measurement, perform routine operations in laboratories assigned such functions.

APPENDIX D

ESTIMATED PERSONNEL REQUIREMENTS

(Omitted)

APPENDIX E

RADIOLOGICAL DEFENSE TRAINING PLAN

(Omitted)

APPENDIX F

ESTIMATED TRAINING REQUIREMENTS

(Omitted)